STEELS FOR THE USER

By R. T. ROLFE, F.I.C., M.I.&S.I., M.Inst.Met.

Chief Metallurgist, Messrs. W. H. Allen, Sons & Co., Ltd.

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NON-FERROUS FOUNDRY PRACTICE

By J. LAING, A.M.I.Brit.F.

and R. T. ROLFE, F.I.C., M.I.&S.I., M.Inst.Met.

In Preparation.

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A MANUAL OF
FOUNDRY PRACTICE

BY

J. LAING, A.M.I.BRIT.F.
WORKS MANAGER
MESSRS. JOHN HALL & SON (OLDHAM), LTD., OLDHAM

AND

R. T. ROLFE, F.I.C., M.I.&S.INST., M.INST.MET.
CHIEF METALLURGIST
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PREFACE TO THE FIRST EDITION

The motive for the present work was the deplorable lack of books dealing with foundry practice in a manner commensurate with the needs of the foundry executive and the engineer of to-day. It cannot be denied that foundry practice has experienced, during the last few years, a fundamental transformation, changing from a basis of crude empiricism to one of scientific and systematic control. Thus, textbooks which in their day were standard works are now obsolete, a matter which has been emphasized on a number of occasions during the past few years. It became obvious that what the foundryman wanted was an account, in one volume, of modern British methods of production, embodying all those details which are vital to successful practical operation, but were not to be found in the textbooks available.

It is hoped that the present work will generally be regarded as supplying that need. It is intended for all connected, in any capacity, with the foundry industry, for, while the basic principles have been dealt with fully, the work proceeds to a comprehensive treatment of the advanced technique, and it should thus appeal equally to the student and the foundry manager. It seemed particularly necessary, for example, to deal systematically with those multifarious design problems which confront the engineer and the foundryman of to-day problems which modern production methods seem only to render increasingly complicated. Operation by the old rule-of-thumb methods, coupled with ignorance, or even distrust, of the scientific aspects of the subject, is an expensive business. It involves reliance upon opinion rather than upon fact. It means working by methods of trial-and-error. It may necessitate the casting of difficult work several times over, before getting it right. It is, in effect, something like trying to sail a vessel to America, without sun, stars or

CONTENTS

CHAPTER		PAGE
	PREFACE	v
I.	THE PRINCIPLES OF MOULDING AND CORE-MAKING	1
II.	CORE-MAKING	26
III.	MOULDING TACKLE	53
IV.	MOULDING TECHNIQUE	63
V.	PLATE AND MACHINE MOULDING	94
VI.	MOULDING AND RUNNING IN RELATION TO DESIGN	119
VII.	LOAM MOULDING	156
VIII.	THE METALLURGY OF CAST IRON	183
IX.	THE MELTING OF CAST IRON	240
X.	SPECIAL METHODS OF PRODUCTION CHILL AND MALLEABLE CAST IRON	266
XI.	NON-FERROUS FOUNDING	277
	APPENDIX	303
	INDEX	306

CHAPTER I

THE PRINCIPLES OF MOULDING AND CORE-MAKING

Foundry Practice deals with the making of metal fabrics, called castings, directly in one operation, by utilising the hydrostatic pressure of molten metal so as to cause the material to take the shape of a mould which has been previously prepared. There is thus no forging, pressing, rolling or welding of the metal in the hot state. Moulding is that section of the industry which is concerned with the production of the negatively-shaped mould, into which the liquid metal is poured, to form the positive casting. Core-making deals with the production of those parts of the mould which are made in a former or core-box away from the main mould, and are assembled later in this mould before it is cast. It should be noted that, although cores are generally used to form the internal shape of the casting, there are many cases which necessitate their employment to form portions of the outside of the mould. Moulding practice is of three main varieties, greensand, dry sand and loam moulding, the moulds being made in all cases of specially prepared sand, suitably reinforced, which is formed into the requisite shape by the use of some kind of pattern. There are differences, however, in the materials, and in the methods of preparation. Greensand moulds are those which are cast with the sand in the same moist state as it is in when the pattern is withdrawn. Dry-sand moulds are given a wet coating of a refractory material, and are dried and baked hard before casting. Loam moulds are shaped in a comparatively wet and very plastic sand, and are also dried before casting.

Foundry Sands. The production of sound castings of good finish, which are more likely to be hydraulically sound than when the castings are rough, depends very largely upon the character of the moulds and cores. Since sand of various kinds constitutes the bulk of the material which is used in the making of these, the qualities required in moulding sands must be considered in some detail. The chief properties that they must possess are fineness, plasticity, adhesiveness, firmness, strength or bond, permeability, refractoriness and durability. All natural moulding sands possess these qualities in varying degree, and, by suitable blending of sands, and the admixture of additional materials, one can obtain moulds and cores of quality suitable for all the various purposes. The chief constituents in sands are silica grains, which resist the heat, and aluminium silicate, or clay, which serves as a binder, and makes moulding possible. Other binders are frequently present in natural sands, and artificial binders are often added. It will be simpler to deal in the first instance with the qualities and preparation of sands used in iron foundry practice. As compared with those employed in non-ferrous work, the differences are of degree rather than of kind, while non-ferrous sands are briefly discussed in a later chapter. The individual qualities are considered in detail below:

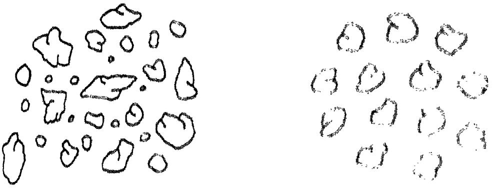
Fineness is requisite, particularly for greensand work, to ensure a smooth surface on the casting. On dry sand, loam and core work, fineness of grain is less important, because the surfaces should be adequately protected with a suitable coating of wet blacking. Greensand moulds, on the other hand, are often merely dusted with dry plumbago or blacking, when the vertical surfaces may be left almost free from deposit. A smooth skin is thus only obtainable when the grain size is not too great, excessive coarseness leading to local penetration of metal during casting, and a rougher finish. As will be seen later, however, the larger the grains, the greater the permeability of the mould to the gases liberated in casting. Thus a compromise in grain size must often be effected.

Plasticity is necessary to obtain a clean impression of the pattern or strickle. In greensand moulding, this demands correct proportioning with water. Clay is very plastic when moist, plasticity increasing with water content. The respective quantities of clay and water control the plasticity of the sand, but green- and dry-sand moulds must not contain too much of either. Clay fills up the interstices between the sand grains, reducing permeability. If the water content of greensand is high, the steam generated by contact with the hot metal is greater than can be passed readily through the sand pores, with disastrous consequences. Too much water in a dry-sand mixture causes parts of the mould to sag out of shape when the pattern is removed. Excess water makes sand pack too densely during ramming, decreasing permeability. One must ram the sand without packing it so close as to be impermeable; yet it must be hard enough to resist erosion during casting. Deep and heavy work is rammed hard, particularly at the bottom end, to resist the hydrostatic pressure of the metal, which may lead to the forcing-back of the mould surface at its weakest point, causing a swelling. Here permeability must be increased in other ways, by venting. Great plasticity is required in loam mixtures, where the mould is generally shaped only with a strickle-board. When moulding with so soft and plastic a material, special methods, discussed later, must be used to preserve the mould shape. The requisite plasticity must not be obtained by using a high clay content. Instead, the content of water is increased to about the proportion used in builder's plaster. This high water content is not objectionable in loam, as it is in greensand, for there is no ramming. Further, excess water tends to keep the sand grains apart, so that the material is more open in texture after drying.

Adhesiveness, as with plasticity, is more necessary in loam, for this, even when green, must hold on to vertical walls, and hang on to the under-sides of plates. Sands also must be adhesive in a lesser degree, to stick to the mould supports, grids, irons, lifters, etc. To promote this, metal plates and supports are usually clay-washed.

Strength or *bond* is cohesiveness, the ability of the sand to hold or bind together. There are two varieties of bond.

Green bond, *i.e.*, toughness, is that of the material when ramming. It is the quality which permits patterns to be lifted readily from the sand, enables moulds and cores to be handled without damage and makes greensand mixtures resist the flow of the metal without washing away. Dried bond is a measure of the hardness, or lack of friability, of the sand after stoving. The basis of all sands is silica, which occurs not only as free silica, a refractory material having no bond, but also in combination with alumina and water, to constitute clay, a powerful bonding agent. When wet, clay is a very plastic, tough and adhesive substance, often present in moulding sands in small nodules, which may or may not be adhering to the silica grains. When the sand is thoroughly mixed and kneaded, as when it is milled, the grains become coated all over with clay, so that, on ramming, a joint is made at each point of contact. A further portion of the silica may occur as orthoclase, which has some bonding power, while bond is also contributed by the presence of hydrated ferric oxide. The bond of the best natural moulding sands for steel is supplied chiefly by this material, clay being present to a much smaller extent. The size and shape of the sand grains also affect bond. If of varying size and shape, as at (*a*) in Fig. 1, a much tougher mass will result by reason of better surface contact than if the grains are of similar sizes, as at (*b*).



(a) (b)

FIG. 1. SHOWING (*a*) IRREGULAR GRAINS, (*b*) UNIFORM GRAINS.

When sands are dried at the usual temperatures in foundry drying stoves, the bond is increased, because clay becomes more adhesive when some of its water has been driven off. If the drying temperature has not been too high, plasticity can be restored by adding water. When clay is heated more strongly, to a temperature which may, however, be much lower than that of molten iron, it is said to be "burnt," all the combined water being driven off, and the bond destroyed, so that it cannot be restored by the addition of water. Too much drying, *i.e.*, "burning," may thus lead to erosion in casting. For another reason, insufficient drying may produce scabbing, a somewhat similar effect. When overheating occurs—as it must always to some extent at the mould face—the burnt clay is no longer of any use as a bonding material, and burnt sand is often used as parting powder for this reason. The metal has often to flow over a projecting piece of mould or core, which must maintain its shape until the metal has solidified, so that the bond must be retained for some time at a high temperature.

Permeability is a measure of the ease with which air or gas can pass through rammed sand. The term, *open* or *free-venting*, is given to sands of high permeability, and *close* or *poor-venting* to those of opposite quality. The pores of rammed sand should be comparatively large, uniform in size and closely interconnected. The contact of the metal in casting makes the air in the pores expand very rapidly. A large volume of gas is also generated from the coal dust and other organic matter often added to moulding sands. In greensand moulds, a large volume of steam is generated from the moisture present. The need of high permeability is thus evident. With sands which are poor-venting, possibly because of hard ramming, the gases cannot escape fast enough from the mould face through the sand, and will blow off the surface of the mould instead, causing a bad scab on the casting. In mould parts which must be very permeable, this is ensured by pricking with a wire, *i.e.*, venting.

The size and uniformity of the grains, their shape, and the amount of clay and other materials present, considerably affect the permeability, this being reduced by the bonding materials and also by coal dust. Sands with small or irregular grains, which pack closer, are less permeable; those with larger or more regular grains are more so. The continuous burning of the sand at the mould face results in an accumulation of fine burnt particles in the floor sand, and tends gradually to destroy the permeability, this being corrected by making regular additions of new sand.

Refractoriness is required to avoid the fusing of the sand at the mould face on to the casting, the mould and cores instead stripping freely, so as to leave a smooth clean skin on the casting. If sand has fused on, trimming becomes much more difficult, and the residual sand has a most prejudicial effect on the tools in machining. The degree of refractoriness is largely controlled by the amount of free silica in the sand, coupled with the freedom from such low melting-point impurities as lime, magnesia, potash and soda. These occur as silicates, some of which may possess, individually, high melting points, but, when mixed together and heated, they readily combine to form a comparatively fusible slag. Silica, on the other hand, has a melting point of about 1600° C., against, say, 1200° C. for cast iron. To increase refractoriness, greensand moulds are dusted with plumbago or charcoal blacking, and dry-sand moulds are painted with a wash of the same material. It is a paradox that the addition, to greensand facing sand, of so combustible a material as coal, increases the refractoriness, and this is discussed later.

Durability is an important quality, enabling one to make smaller additions of new sand. The destructive agent is the high temperature, causing the "burning" of the clay, and also tending to make the silica grains crack and disintegrate. The heavier the work, the more rapid is the deterioration, and the greater the quantity of new sand required. When really large castings are made regularly when the sand at the mould face may remain at a red heat for two or three days—fairly large quantities of new sand must be periodically introduced, or the floor sand will soon reach so "burnt" a condition that serious washing or scabbing may occur. The feel of the sand is a good criterion of condition. When burnt, it feels rough, with an absence of that silky feeling so characteristic of floor sand when it has been prepared for small work. It should be noted that, unlike clay bond, ferruginous bond is not destroyed by contact with molten metal, and the more durable sands often contain a higher proportion of the latter.

All natural moulding sands possess these various qualities in different degrees, and they are blended by the founder according to the class of castings required, such other materials as coal dust, chopped straw, manure, hops, sawdust, blackings, crude oil, etc., being also added. The mixtures may be strengthened by the addition of clays, or weakened by the addition of silica sands. Coal dust is used in greensand facings, the backings being floor sand; while, for cores, manure, sawdust, and other materials are employed. In some districts, a mixture of new and floor sand is used without any addition of coal dust, but only on the lightest of work. Some very open sands can also be used for dry-sand and loam mixtures, without animal or vegetable matter being added. This is, however, exceptional, and the use of such a mixture for large intricate castings would probably prove false economy. Moulding sands may also be made synthetically from clays, silica sands and some of the other ingredients mentioned. Success in preparing moulding sands requires long experience and sound judgment, which enables one to obtain a suitable balance between the various and somewhat incompatible qualities required. The properties and mode of operation of the different constituents should be considered in some detail.

Natural Moulding Sands. These may be red, light brown or yellow in colour. The red are from the Bunter (Triassic) deposits, materials of the same geological age, and with similar compositions and properties, being obtained from a variety of sources. The brown and yellow sands belong to a number of different geological ages, varying in composition and properties accordingly. The approximate compositions of moulding sands in general use are as follows: silica 79-89%; alumina 3-9%; iron oxide 1·5-4·5%; lime 0·2-2·5%; magnesia 0·1-1·6%; potash 1·0-3·0%, and soda 0·1-1·5%. The actual figures for some sands from the authors' practice are as follows:

Description of Sand	Mansfield Red Sand	Worksop Red Sand	Radford Red Sand	Erith Sand	Loam Sand "Mild Clay's" Box End, Bedford	Yellow Sand Rushes Ford, Bedford	[illegible] Leighton Buzzard sand	Yellow Leighton Buzzard sand
Geological Deposit	Bunter (Triassic)	Bunter (Triassic)	Bunter (Triassic)	Eocene	Oxford Clays	Oxford Clays	Lower Greensand	Lower Greensand
Silica % ..	88·69	87·90	86·03	85·84	85·80	91·06	86·88	88·92
Alumina % ..	5·47	5·65	8·70	5·07	6·16	4·92	3·30	1·79
Ferrous and Ferric Oxides %	1·37	2·20	0·90	2·44	1·81	1·00	2·40	3·59
Lime % ..	0·20	0·60	1·37	0·38	0·59	[illegible]	[illegible]	[illegible]
Magnesia % ..	0·31	Tr.	0·44	0·40	0·22	0·06	[illegible]	[illegible]
Alkalies % ..	2·62	2·15	0·79	2·25	2·42		3·4[illegible]	1·41
Combined Water % ..		1·50	1·77					
Loss on ignition % ..	1·34			3·52	3·00	1·65	2·78	2·83
Total % ..	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

The characteristics of the individual constituents of the various sands and of the other materials frequently added to them are dealt with below.

Silica or silicon dioxide (SiO_2) is the chief constituent of sands, which arise from the disintegration of rocks in which quartz, a crystalline form of silica, is the most abundant mineral. The hardness and chemical stability of quartz enable it to survive after the associated minerals have largely disappeared. Seashore and silver sands are thus composed chiefly of silica grains which have become water-worn and rounded. Silica is a very refractory mineral, with a melting point of some 1600° C., so that furnace temperatures as used for cast iron and most non-ferrous alloys do not cause fusion, but may lead occasionally to cracking and disintegration. Silica will combine with soda, potash or lime when heated, to produce silicates having melting points much lower than that of pure silica, and the use of limestone in cupola practice as a flux for sand is well known. In blast furnace practice, silicate of alumina, or clay, is fusible only with difficulty, but fusible silicates of lime or lime and alumina are produced by the addition of limestone. The contents of lime and other fluxing impurities in foundry sands must therefore be kept low. Some other constituents, as alumina, must not exceed certain limits. The shrinkage and cracking seen in clayey ground in dry weather is familiar to all, and this is found, after stoving, in loam mixtures too rich in alumina. Silica sand should be added, to reduce the bond and make the dried sand more friable. Supplies of silica sands are found at several inland localities in Kent, Bedfordshire, Yorkshire and elsewhere, while large quantities are obtained from the seashore, the Southport district being one of the most famous. The silica content may be as high as 98, and is frequently higher than 95%.

Clays. These consist of varying proportions of alumina, Al_2O_3; silica, SiO_2, and water. They differ markedly in composition, those high in silicate of alumina (clay), with only a little free silica, being termed *strong* or *fat*; while those low in clay, and high in free silica, are termed *weak* or *mild*. China clay is one of the purest forms, and fireclay—consisting of silicate of alumina with an excess of silica, and only small quantities of the low melting-point impurities, lime, magnesia, potash and soda the most refractory. Clays possess in a marked degree the qualities of adhesiveness, bond and plasticity. They strengthen moulding sands by holding the grains together, and are often added to weak moulding sands for this purpose. Too much will confer upon the sand some of the impermeable quality of the clay, and one cannot cast quietly into moulds made of such a mixture.

Oxides of Iron. The red, brown and yellow colours of the sands are due chiefly to these, which are frequently present in colloidal form, possessing great surface energy and acting therefore as strong bonding agents. There are several forms of iron oxide, of which one, ferrous oxide (FeO), will combine readily with silica to form a fusible silicate. The proportion of ferrous oxide in all the well-known sands rarely reaches 0·5%, so that this apparently dangerous reaction should not often lead to serious trouble.

Lime, Magnesia, Potash and Soda are present as carbonates or silicates, the individual melting points of which may be comparatively high. Their reactions when heated may lead, however, to the production of more fusible compounds, with consequent reduction in refractoriness.

Chopped Straw, Horse Manure, Hops and Sawdust. These and similar materials are added to sands to increase the permeability. In drying, they retain moisture until the mould or core has set firmly, and then become dry themselves, when they shrink considerably, and may be partly burnt away, leaving additional spaces for the escape of gas. Horsehair may be added to loam mixtures to increase green bond or toughness, but it is generally more economical to use a sand which is naturally stronger.

Coal Dust. This is always added to greensand mixtures to enable the mould to strip cleanly. It gives rise, in casting, to a thin film of gas on the mould face, preventing overheating and expansion of the sand grains, and resisting the penetration of the metal until it has set. The reaction between the heated coal, and the oxygen in the pores of the sand, serves to maintain a reducing atmosphere, and prevent the formation of an iron silicate which would adhere to the casting. The proportion of coal required to accomplish these reactions varies considerably with the thickness of the casting, from about 20 per cent., for a casting 4 ins. thick, to 5 per cent., with one only ¼ in. thick. It is thus difficult to decide on a suitable mixture for a casting varying considerably in section. About 10 per cent. is a usual proportion. Less may be added when a larger proportion of old sand, still containing unaltered coal dust, is used. All the sands should first be sifted, the coal dust added, the whole sifted, and the requisite quantity of water then incorporated. A free-burning coal, with a high volatile content, should be used, when the percentage of coal can be lower. A coal giving good results showed: moisture, 1·39%; volatile matter, 35·81%; fixed carbon, 48·35%; and ash 14·45%.

For thin light work, the grade sold as "Superfine" is most suitable, the fine grade being used for medium work. Foundries making very heavy work in greensand sometimes use the grades known as "Medium" and "Coarse," because there is less reduction in permeability. [The use of too much coal dust, especially of the free-burning variety, gives a peculiar ribbed effect on the surface, sometimes known as "mapping." The more violent reaction, and the liberation of much more gas, gives rise to cracks on the mould face into which the metal penetrates.] [For dry-sand work, the refractory coating of blacking generally renders the use of coal dust unnecessary, but it may sometimes be utilised with advantage.] Where a small piece of sand projects into a heavy mass of metal, it is sometimes difficult to prevent the metal penetrating, if only the usual wet blacking wash has been applied. The admixture of a little coal dust will often overcome the difficulty, and enable the casting to be stripped cleanly.

Blackings and Crude Oils. Blackings are frequently added to greensand mixtures for light castings, to obtain a smooth skin. Blacking increases refractoriness and reduces permeability. When blacking is used, the coal dust can be decreased, slightly offsetting the extra cost. Dry-sand and loam mixtures required to be particularly refractory often carry a proportion of mineral blacking, when the amount of bonding material must be increased, or the dried sand may be weak and friable, because the blacking between the sand grains reduces the binding action of the clay. In greensand facings, the effect of crude oil resembles that of coal dust, a gas film being formed on casting. Thus, if crude oil is used, the coal dust can be reduced, while still obtaining a clean smooth skin. The use of crude oil leads to fairly strong fumes being given off after casting, and, in a low and badly ventilated shop, these can be very disagreeable. Further, the continuous use of oil in the facings causes the floor sand to become slightly contaminated with it, the oil being only partly destroyed in casting. This oil hinders the preparation of the sand, retarding the incorporation of the water added.

The Choice of Sands. The sands used must be such as will give good castings of the particular class required and must therefore possess in a definite degree the properties previously postulated. Supplies of good moulding sands are abundant in many parts of the British Isles, and the great development of the foundry industry in the Birmingham and Manchester districts is due to their large deposits of sands of excellent quality, as at Kidderminster, Stourport and Stourbridge in the former, and Ormskirk and Runcorn in the latter area. Among other well-known sands are those of Mansfield, Lenton, Worksop, Doncaster, Erith and Belfast. A vital factor is the cost per ton delivered to the foundry, while an important consideration is the proportion of old sand that may be used with that selected, while still maintaining the essential qualities. Many suppliers are able to sell at very low rates at the pit, and a foundry situated close at hand has a corresponding economic advantage. Familiarity with a particular sand is a great help in mixing and use, and any of the above sands will give excellent results if handled intelligently. Those from the Manchester district are possibly the least difficult to prepare, being naturally free-venting, and supplies are much more uniform in bond than with many of the other sands. Some of the Erith sands vary considerably in clay content, and require more careful watching. Unless some local supply of proven quality is available, one should use one of the well-known natural sands, the nearest of which may be a long way from one's foundry. There is usually a choice between two or more sands from the same district, varying slightly in strength of bond, grain size, or both, and one naturally uses the cheapest which possesses the characteristics required. Rail freight charges may be three or four times the cost of the sand at the pit. Where water transport is available, freight charges are much lower, and sand can be shipped considerable distances at comparatively low rates.

For small intricate castings, a fine-grained sand with a good bond should be used. The extra toughness will enable the pattern to be withdrawn with much less disturbance of the projecting portions of the mould. A fine-grained sand gives a much smoother skin on the castings, and the reduced permeability due to the smaller grains and the greater bond is not serious in small work. Suitable sands for this class of work are those of Erith, Mansfield, Belfast, Stourport and Stourbridge. Heavier castings demand more permeability, and those of larger grain from Ormskirk, Runcorn, Doncaster, Lenton and Worksop are therefore very suitable. The greater refractoriness required in the mould for large work is generally obtained by the increased protection to the face which is afforded by a thicker coating of blacking, or a more refractory dressing. Sands from the Lancashire district, Erith, Belfast, Birmingham and many other localities are excellent for general purposes.

Greensand Moulding. The greensand method is in general use for small work; it is employed in some districts for work of medium size, and in districts where — as in the West Riding of Yorkshire and parts of Lancashire — the sands are particularly suitable for this class of work, quite large castings are made in greensand. The method has several advantages. The cost and delay involved in drying the moulds are saved, and a correspondingly larger output can be ~~obtained~~ from a given floor space. One can similarly work ~~with~~ a smaller amount of moulding tackle, boxes, lifters and so forth. For small work, it has, indeed, no disadvantage, unless particular properties are required in the castings. For larger work, however, the risk of defective castings is much greater than when the mould is dried. The large volume of steam may cause blow-holes, and the weaker sand may scab or wash under the flow of the metal.

Mixtures for Greensand. When making light castings, the sand is little affected by the molten metal. It still contains much unburnt coal, and is comparatively free from silt, arising from the "burning" of the clay. Thus the floor sand remains in a relatively good condition, and a higher proportion of old sand can be used. A typical mixture for light work is as follows:

Greensand Mixture for Light Work

Floor Sand	6 parts	..	80%
New Sand	1 ,,	..	13·33%
Coal Dust (superfine grade)	½ ,,	..	6·66%

Fine-grained sands, as Erith or Mansfield, are recommended, as giving a much smoother skin to the castings. With castings having a large surface, one should use a greater proportion of floor sand in the facing, and keep the mixture rather dry. The extra dryness will not reduce the fluidity of the metal so much, and a more sharply run casting will be obtained. The larger the work, the more rapidly will the floor sand deteriorate, and the greater the proportion of new sand used. For more general work, varying from about ½ to 1¼ in. in thickness, the proportions of new sand and coal dust must be increased, a suitable mixture being as follows:

Greensand Mixture for General Work

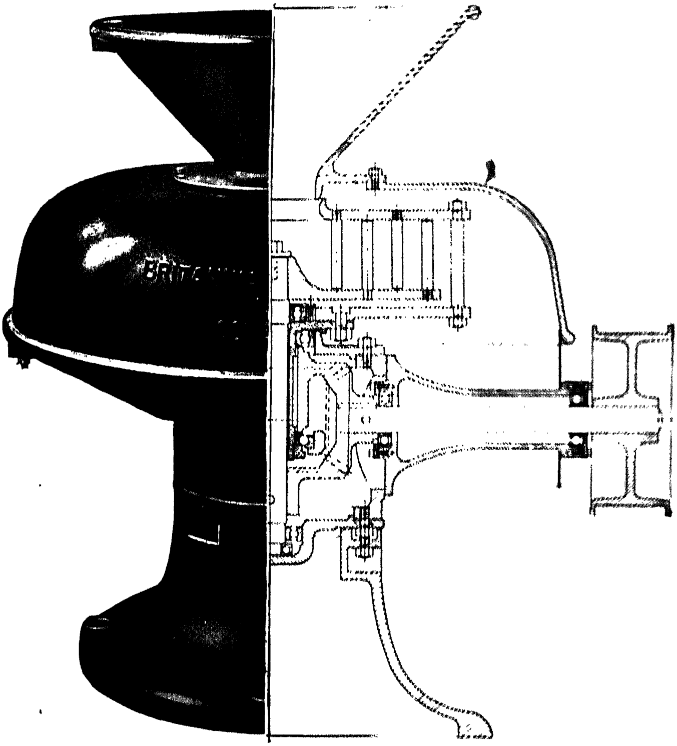
Floor Sand	8 parts	59·3%
New Sand	4 "	29·6%
Coal Dust (fine grade)	1½ "	11·1%

When a particularly good finish is required, as for castings for the enamelling trade, talc may usefully be added to the sand, a basis mixture being given below. Slight variations in these proportions may be required, according to their respective qualities:

Greensand Mixture for Smooth Finish

Floor Sand	10 parts	57·1%
New Sand	4 "	22·9%
Coal Dust (superfine grade)	1½ "	8·6%
Carbon Blacking	1½ "	8·6%
Talc	½ "	2·8%

In facings for very heavy work, of 2½-3 in. in thickness, still more new sand must be used than with the Greensand Mixture for General Work, above, while the coal dust may constitute 20 per cent. of the whole with advantage. One should also use a coarser and more permeable sand, as Lenton, Worksop or one of the Lancashire red sands. The mixtures are only suggested as a working basis, for the percentage of new sand required must depend upon its individual properties. The proportion of coal required to obtain the best skin on the castings must similarly vary



[Alldays & Onions, Ltd.

FIG. 2.—"DUPLEX" FOUNDRY SAND MIXER

To face p. 15]

with its proportion of volatile matter, ash and so forth. Mineral blackings are frequently added to greensand facings for light work, but, because of the reduction in permeability, are seldom used for heavy castings.

Greensand Mixing. Mixing by hand is the old method, still practised in some small foundries. When properly performed, it can produce a facing sand of high permeability, but the bond is always lower than when a mechanical mixer is employed. The procedure is to spread, in a low heap on the floor, the sand present in greatest proportion in the mixture; on top of this, the sand present in the next largest amount, and so on, until the heap is finished, and consists of a series of layers, decreasing in quantity to the top. The whole is turned over with a spade, is well trodden, and turned over a second time, being passed finally through a ¼-in. sieve, when it is ready for use. One must be sure that the moisture content is correct at the time of mixing. The facing sand should stand a little while after mixing, when the moisture becomes thoroughly distributed.

Mechanical mixing is now commonly practised. Several types of mechanical riddle are also used for sifting the sand after it has first been mixed by hand, but this hardly constitutes "mixing." Almost all of the mixing operations can be performed mechanically, however, and one of the earliest types used in greensand work is the centrifugal sand mixer, an example of which is seen in Fig. 2. The sand is laid out on the floor, just as for hand mixing, and then sliced down with a shovel and fed into the central hopper. Falling on to the cone, it is thrown centrifugally outwards through the spinning prongs and against the outer casing, when it falls to the ground. A thorough mixing results, the bond being well developed. The position of the hopper makes feeding somewhat laborious. Fig. 3 shows the Royer sand mixer and aerator, a more modern machine, which makes excellent greensand facing. The sand fed into the hopper falls on to an endless leather belt, travelling at about 900 feet per minute, and carrying thin steel teeth, by which means it is thrown forward through a species of steel comb, thorough mixing being effected, while the scrap falls out from the front of the hopper. This machine has several advantages. It is easy to feed, and the throwing forward of the sand in an almost continuous stream enables one to direct it readily into a hopper or storage bin. It is much used for reconditioning floor sand, and is particularly useful in the preparation of sand for machine moulding.

Dry-Sand Moulding. This method possesses several advantages over the greensand method, the greatest being the lessened risk of the casting being faulty. When a mould is properly dried, there is small likelihood of washing away or scabbing in casting. Medium and large castings made by this method are always cleaner on the top face, blow holes, gas-holes, sand inclusions and other defects being much scarcer than in greensand castings. Large and intricate castings can be moulded more quickly, because the amount of venting, sprigging, etc., can be reduced, these safeguards being sometimes unnecessary in dry-sand work. Surfaces and corners of castings are less chilled. The disadvantages are the extra expense involved in drying the moulds, the extra handling of the moulds to and from the stoves, the greater number of moulding boxes required for the same output, and the delay in the production cycle by reason of the time taken in drying.

Mixtures for Dry-Sand. As with greensand, facings for dry-sand necessitate the use of a higher proportion of new sand when making heavy castings. Most foundries, however, use a standard mixture for nearly all their work, the only exceptions being for large and heavy castings, quite out of the usual run of work. In such cases, a stronger facing is made up, and reserved for this purpose. Typical mixtures are as follows :

Mixture for	Small and medium work	Ordinary heavy work	Extra heavy work
Floor Sand	13 parts	11 parts	10 parts
New Sand	8 ,,	9 ,,	10 ,,
Horse Manure or Sawdust	1 ,,	1 ,,	1 ,,

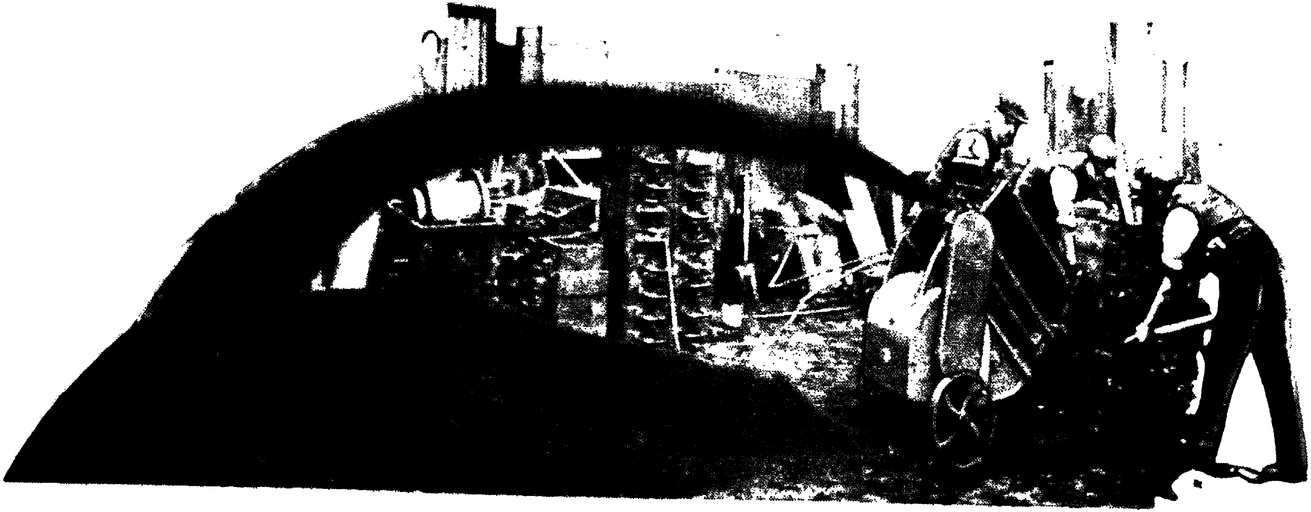


FIG. 3. THE ROYER SAND MIXER AND AERATOR

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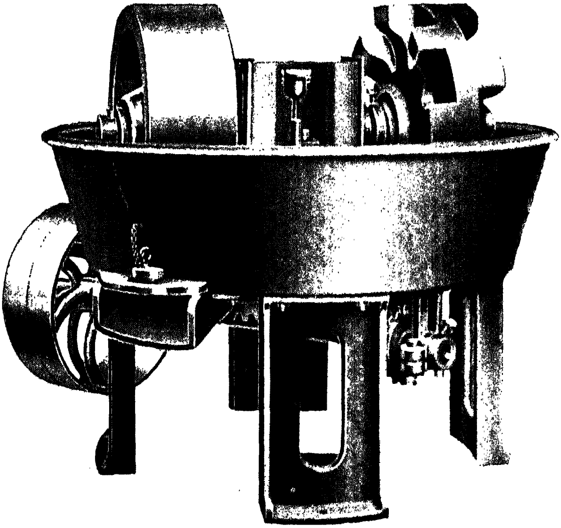


[*Alldays & Onions, Ltd.*

FIG. 4.—CHILEAN MILL, FOR GRINDING SAND AND LOAM

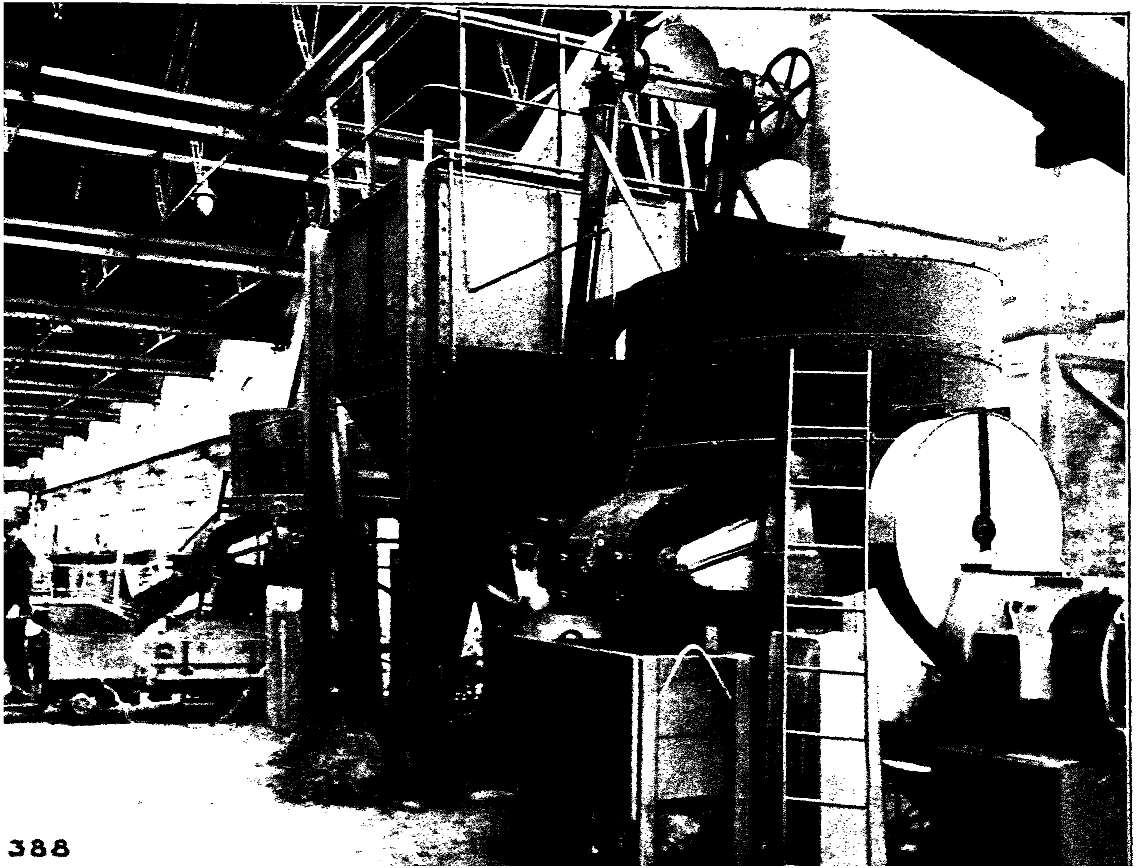
For the extra heavy work, the most open and refractory sands should be used. If the bond is too low, one part of ganister should be added to the mixture.

Dry-Sand Mixing. A good green bond helps in moulding, but too much causes low permeability. When the mould is dried, however, the balance is again restored, and all dry-sand facings are therefore milled, in some way or other, to develop their bond and improve their moulding properties. Although, during the last few years, many new sand mills have been developed, the edge runner or Chilean mill, as in Fig. 4, is still commonly used. In older types of this mill, two plain rollers are often used, when the sand tends to aggregate into hard flat cakes. This is largely avoided by the use of a chopping wheel, shown at the right of the figure. One usually mills for five to seven minutes, depending upon the efficiency of the mill, and the quantity charged. Some of the modern mixers are undoubtedly better, causing less damage to the sand grains. The foundry sand-preparing plant shown in Fig. 5 incorporates two Simpson mixers, having two narrow revolving rollers, the sand being turned in front of these by ploughs or scrapers. When used as a separate unit, a bucket-loading device enables it to be charged with a minimum of effort. It can be fitted high enough to permit a wheelbarrow, truck or other sand-conveying apparatus to be run under the discharge chute. Fig. 6 shows another new mixer, consisting of a revolving table fitted with two large and comparatively light rollers, under which the sand passes. The wide rollers give rise to a skidding action, which rubs the bonding material round the silica grains. The four cutting blades break up the sand on the bottom of the plate. Discharge is effected by adjusting a side plate, which scrapes the sand off the bottom at a given point.

Loam Moulding. The outstanding feature of loam is its great plasticity, for the mould can often be made from a strickle or part pattern, much of the usual cost of pattern-making being saved. The moulds are hard, strong and highly permeable to gas, so that there is usually little scabbing or washing in casting. The cost of making castings in loam may either be greater or less than in sand, depending upon design. The chief disadvantage of loam is that one must take certain precautions to remove excess water from it, or the material may sag and distort, before the mould is dry. Again, the making of special tackle is often necessary. Before making any casting in loam, it is thus necessary to make sure that the method will be economical.

Loam Mixtures. The mixtures recommended for dry-sand will make good facings for loam, if they are milled with additional water to bring them to the right consistency. Loams can also be made by bonding silica sands with suitable clays, but these burn more readily than those made with the usual sands, and require more care in drying. If, after drying, there is any tendency to crumble, the mixture should be strengthened, either by increasing the proportion of new sand, or the addition of a suitable clay. If, on the other hand, there is much shrinkage and cracking during drying, the clay content is probably too high, and the mixture should be weakened by the addition of silica sand. Building loam or black loam is made by adding a little weak clay, sometimes as clay water, to the floor sand, and milling with the correct amount of water. The Chilean mill is almost universally adopted for the mixing of loam. Owing to its soft and plastic nature, many modern sand-mixers are not suitable for it.

Core Sands and Core Loams. These are made as dry-sand and loam facings, but must be strengthened by adding a little more new sand. Since cores are often surrounded almost completely by metal, one should also increase the proportion of animal or vegetable matter, to increase the permeability. Various artificial core binders, in conjunction with sharp sand, are in general use to-day, and considerably increase the speed of production. Cores made with artificial binders are stronger, needing less reinforcement. Owing to the uniform grain size of the sharp sand used, they are much more permeable. They are more true to shape after drying; while they become "burnt" after casting and are much



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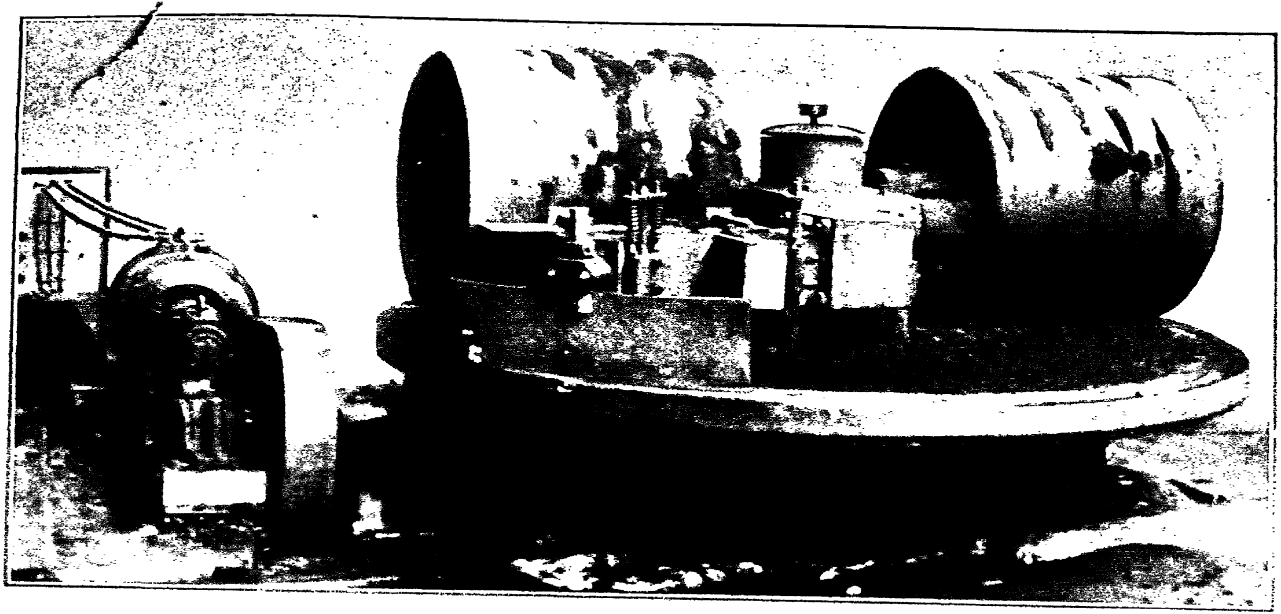


more readily removed — tapping with a hammer being often all that is necessary — a particularly valuable property where, as often, the core has to be extracted through a very small orifice. These binders may be either solids or liquids. Solid binders include flour, dextrin, resin and proprietary mixtures. Liquid binders include fish oil, linseed oil, resin oil, molasses and proprietary liquids. These are usually oils, suitably mixed with molasses, gums, etc. The solid binders are more difficult to incorporate, flour in particular being often unevenly distributed, when the aggregations lead to gasification in casting and tend to cause blow-holes. Liquid binders are more readily mixed, and give better results in practice.

Oil-Sand Cores. Oil has the advantage of making cores damp-proof, so that they can be left about the shop, or in greensand moulds, for a considerable time, without requiring drying again. The cores must be strong enough to stand up before and during drying, except when special supports are used, and — since the employment of plain oils with sharp sand does not give any green bond — molasses, dextrin, core gums, etc., are added when this property is required. Mixtures possessing green bond produce a core with smoother surface, but do not flow so readily in the core box, requiring more ramming. For very light work, one part of core oil to 40 parts of sharp sand may be used, the proportion of binder being increased as the work gets heavier, until it may reach one part to 25 of the sand. An excellent sharp sand for the purpose is found on many parts of the seashore, those of the Southport and Birkdale districts being largely employed. Various inland silica sands, as those of Bedfordshire, Kent and Yorkshire, are often used.

When additional green bond is required, about 10 or 15 per cent. of red sand may be substituted for an equal quantity of silica sand, this also serving to increase the resistance to the penetration of the metal, where a comparatively small core is surrounded by a considerable mass of metal. Red sand should only be used in oil-sand mixtures in such circumstances, or where increased green bond is essential, for it reduces the normally high permeability of the mixture;

while, owing to the natural bond in the red sand, there is much greater difficulty in removing the cores after casting. The amount of oil necessary in the mixture is such as will just cause a thin layer to be smeared over the silica grains. Any excess will tend to clog up the passages between them. After drying, each grain is cemented to its neighbours, as in Fig. 7 (*a*). On examining an oil-sand core, after drying, under the microscope, comparatively large voids, as in Fig. 7 (*b*), will be seen. It is the existence of these which makes oil-sand cores so permeable. If to an oil sand mixture composed of coarse-grained silica sand, red sand is added, the smaller grains of red sand can be seen adhering all round the silica grains, as in Fig. 7 (*c*), with resultant increase in green and dry bond, and loss of permeability. Although oil-sand mixtures can be made in the Chilean mill, it is preferable to use a mixer specially designed for oil-sand work. There are a number on the market, one of the most recent types, the Rotoil, being seen in Fig. 8. It consists of a stationary pan, fitted with three fixed blades set at an oblique angle. Under these rotate another set of blades, when an excellent rubbing action is obtained, such as will effectually smear the oil over the sand grains.

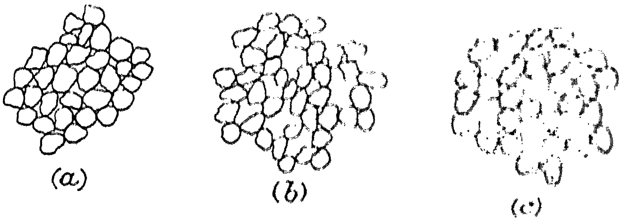
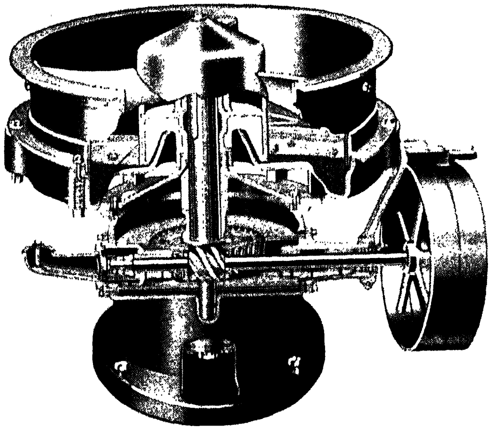


FIG. 7.—(*a*) THEORETICAL CEMENTING OF GRAINS; (*b*) VOIDS IN AN OIL SAND CORE; (*c*) DISPOSITION OF RED SAND IN AN OIL SAND CORE

Sands for Non-Ferrous Work. In contrast with cast iron, the pouring temperatures of most of the non-ferrous alloys are considerably lower, and refractoriness is less important. Some alloys, as leaded bronze and some of the phosphor-bronzes, are, however, very penetrative, and fineness of grain is essential. The finer grades of Mansfield and Erith are



[*Fordath Engineering Co.*

FIG. 8.—SECTIONAL VIEW OF ROTOIL SAND MIXER

[*To face p.* 20

admirable for non-ferrous work. The sand is little affected by casting, and can be used repeatedly, with very small additions of new sand. For small general work, the sand needs little preparation, it being only necessary to mix it well by passing through a riddle, keeping it preferably on the dry side. A small quantity is then further sifted on to the pattern face, before filling up with the prepared sand. If the sand is too wet, the metal may penetrate into it, making the casting rough and unsightly. For very small work, a better skin is obtained by milling the floor sand with a small quantity of new sand, adding a little used machine oil or crude oil, when a tough and easy-working sand is produced, giving an excellent finish to the castings. In larger castings made by the dry-sand method, fineness of grain is less important, because the mould faces are given a protective coating of wet blacking, or of terra-flake and plumbago, which effectually prevents penetration. Many local sands and so-called "mild clays" make good non-ferrous dry-sand facings when suitably mixed.

SAND TESTING

In the case of naturally-bonded sands, it is doubtful whether any of the very elaborate systems of sand testing justify the cost. For synthetic sands, however, some method of testing seems essential, and it is doubtless for this reason that sand testing has come into greater vogue in America, where synthetic sands are much more used. There are a number of simple tests, which afford to an experienced man, familiar with the grade of sand, a sufficient indication as to its suitability for the work in hand, and such tests are always worth doing. It will be clear that, through long practice in the working of a particular sand, a special moulding technique is evolved, producing good castings, and, when practice has thus become standardised, the indications afforded by these tests may constitute all the control that is necessary. When however, for any reason, a foundry changes over from one supply to another, the tests may give anything but the desired results, especially if the new sand possesses a lower permeability figure.

Moisture Tests. The water content of sands varies usually between 5 and 7 per cent., being largely absorbed by the clay. If the water content is excessive, the clay becomes thin and fluid, the volume increasing with the water content, and reducing the pore spaces in the sand to a corresponding degree. Wet greensand facings have therefore a low permeability figure, and may cause scabbed or blown castings. Wet sands, after being rammed, thus dry much denser than do drier sands. The fluid nature of the clay permits the silica grains to bed more closely together. The shop test for moisture is to pick up a handful of the mixed sand and work it over the fingers with the thumb. Even a highly experienced man may not be able to tell you the approximate percentage of water by this method, but—what is very much more important—he will, if he is used to the sand, be able to tell you if the moisture in it is correct. Fine sands, where the grains have a greater surface area, will always carry more water, without feeling more moist to the touch, than will coarse sands. The percentage of moisture can be determined accurately enough for all practical purposes by weighing a sample, and drying it on a steel or cast iron plate over a fire. Care must be taken not to get the sand too hot, and it should be dried until there is no further loss of weight, when the loss, as compared with the original weight, represents the moisture. There are also various rapid moisture testers upon the market, which constitute an invaluable check upon the moisture content of greensand mixtures after they have been made. It should be said, however, that, owing to variation in the distribution of the water, it is extremely difficult—even when the best equipment is available—to assess the moisture content in any particular batch of sand, before it is mixed. It is therefore necessary to employ a trained man on this work, if reasonably consistent results are to be obtained.

Test of Grain Size. The mechanical or sieve test is a valuable one, for it enables one to compare different consignments of the same sand for uniformity in grain size, or to contrast with each other the relative grain sizes of different sands. It is upon the grain size that the permeability of a ability may both be expressed and determined quantitatively, however. It can be expressed as the volume of air in c.c. passed per minute through a specimen of 1 sq. cm. in area, and 1 cm. thick, by a given pressure, and may thus be calculated as follows:

$$\frac{\text{c.c. of air} \times \text{height of specimen in cms.}}{\text{pressure in grams} \times \text{area of specimen in sq. cms.} \times \text{time in min.}}$$

The British Cast Iron Research Association has devised an apparatus to determine the time taken for gas under a standard pressure to pass through a rammed cylinder of sand, so as to ignite at the top of the cylinder. Moisture and density of ramming must of course be constant. The drawback to this, and in fact to all tests made in the cold, is that the conditions are not such as obtain in service, where the molten metal gives rise to various reactions which are not found in cold columns of sand through which gas or air is passed and measured.

Bond Tests. The simplest test is to squeeze a small quantity of the sand tightly in the hand, so as to compact it into a lump, which is then broken in two, more or less readily, according to the toughness of the sand in the green state. Another method involves the ramming of a core, of about 1½ in. square section, and 14 in. long, as evenly as possible, after which it is laid on a flat plate, and gently pushed, so that it begins to project over the edge. The process is continued, until the overhanging portion can no longer be supported, and breaks off. The maximum length which can be projected in this manner gives a direct measure he quantity of green bond. The B.C.I.R.A. has a kind pring-balance machine for testing green bond, by putting ore, 1 in. square, into compression. In all these tests, is essential to keep the moisture figure constant, a somehat difficult matter. Various tensile, transverse and hardness tests are also made on dried cores.

Chemical Analysis. Although chemical analysis might appear to be a test of the first importance, it is not particularly sand partly depends. Some impression of the size and shape of the grains can be obtained by examining, with a pocket lens, a little of the dried sand, spread very thinly on white paper. One can thus obtain some indication of the probable behaviour of the sand in service. A more exact method is to determine the grain size quantitatively, by shaking a weighed sample of the sand for a given time on each of standard sieves of 120, 100, 80 and 50 mesh, respectively. Other sizes can of course be used. The test is more conveniently made, not by shaking on each sieve separately, but on all at the same time, by using a box, provided with a tightly-fitting lid, the sieves being arranged in the box in order, with the coarsest at the top. A weighed quantity of dried sand is placed in the topmost sieve, and the whole is shaken for the definite period, after which the quantity remaining on each sieve, and the fines in the bottom of the box, are weighed, and calculated into percentages of the whole. By such mechanical analysis, a good estimate of the permeability of the sand can be made. The free-venting sands are those which leave a large proportion of their grains on the 80-mesh sieve, and where only a small percentage of fines, or silt, falls into the bottom of the box. When sifting sands which are very fine, a large proportion may fall through all the sieves, when little information will have been obtained. Again, if the fines are only of small amount, it may still be desired to investigate their character a little further. These finer grades may be classified more exactly by the use of water-currents of suitably adjusted velocity, the very fine silt being first removed ; next the particles a little coarser, and so on, this process being known as **elutriation.**

Permeability Tests. Since the permeability of the sand depends partly upon the size of the grains, and partly upon the amount of clay, etc., contained between them, examination with a lens will afford some information as to the permeability. Another method utilises the principle of separating the silica, and the clay and other bonding material, into two layers, by agitation with water, so that the relative amounts of each can be roughly determined. Little indication is given of the relative sizes of the silica grains. Permeuseful as an indication of the behaviour of a naturally bonded sand in service. It certainly constitutes some guide as to the value of an unknown sand, whose utility is in question, serving, for example, as a means of detecting fluxing compounds in sands ; but it does not show the relative binding powers.

CHAPTER II

CORE-MAKING

The manufacture of plain cores needs little skill and the foundry student should always obtain his first practical experience on the core-bench. The primary use of cores is to facilitate the production of moulds, and, in any consideration of moulding, the use of cores must be constantly referred to. Core-making should thus receive prior attention, and does here.

Cores. A core may be defined as an internal part of a mould, made in a separate former or core-box away from the main pattern, and afterwards assembled in position in the mould before this is cast. Cores are usually the portions forming holes or pockets in castings. In practice, however, any part of a mould which is shaped in a former or core-box is called a core, even though it may be a plain slab, used merely to form a flat outside wall of the casting.

Core Prints. These are additions to the pattern which are not shown on the drawing, and form seatings in the mould by which the cores are correctly positioned for casting. The pattern in Fig. 9 (*a*) shows a core print, denoted by shading, at B. The core, which at this end is the exact size of the print, fills this up, so that the termination of the casting is indicated by the unshaded portion. It is only when cores are rather long in proportion to their width that a top print is necessary, to hold them in their correct position. If the core has a large base area, and is comparatively short, the top core print need not be used, the core being then made so as just to touch the top, or any other face of the mould, as at A in Fig. 9 (*a*). No location seating is provided at this point, this portion of the mould, and also the corresponding part of the pattern, being termed print (not *a* core print).

Uses and Advantages of Cores. Cores are chiefly used to shape those parts of the casting which are too difficult or too costly to form by means of the pattern. The chambered centre hole in the pulley boss in Fig. 9 (*b*) would always be produced from a core, formed in a box as in Fig. 9 (*c*), from which two halves are made and joined together. Cores are also used to make parts of the mould more accessible, as with a casting similar in section to that in Fig. 10 (*a*). By forming the inside shape with a core, C, the flanges AA present no difficulty, being in the bottom of the core-box, while the flanges BB are unscrewed from the pattern, and withdrawn from the sand into the space in the mould to be occupied finally by the core C. Another use for cores is to cover projecting parts of a pattern when one desires to make the moulds on a machine. Such projecting pieces interfere with the flow of the sand, and, whether the ramming is done by jarring or squeezing, a soft place is left under the projection. Fig. 10 (*b*) shows a pattern inverted for ramming, the shaded portion representing a core print used to fill up the under-side of the projecting piece A, this permitting any vertical pressure to pack the sand tightly all over the face. When the pattern has been withdrawn, the core print is filled up with a core of the same shape. Other uses of cores will be described later. The making of a core involves an additional operation, and their use must always be considered in relation to the cost of production.

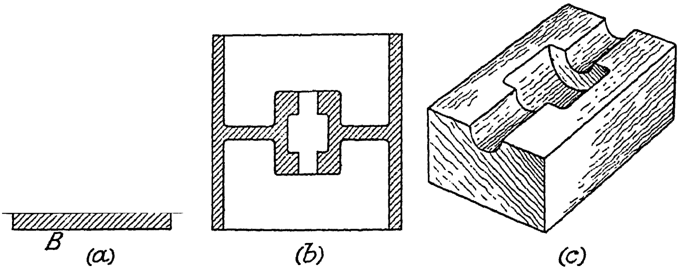


Fig. 9.—(*a*) Showing Core-Print at bottom, and "Print" at left-hand side; (*b*) Chambered Recess in Pulley Boss, formed by Core; (*c*) Half Core-Box for making Core for Pulley Boss

Types of Cores. Cores are divided into greensand, dry-sand, loam, oil-sand and chill cores. Greensand cores are made from sand mixtures as for greensand facings, and are used just as they leave the core-box. In iron founding, their employment is limited to occasional urgent jobs, when there is no time for drying; and to castings consisting of a thin outside shell—rainwater pipes, and the like—where the liability to fracture is much reduced by using a soft core. In the founding of aluminium, a metal which not only has a higher contraction in cooling, but is also very brittle when hot, greensand cores are used extensively. Dry-sand cores are those most commonly used, and are superior in various ways to those of greensand. They can be handled with little risk of damage. The absence of moisture makes the occurrence of blow-holes or scabs less likely. Because of their coating of black-wash, they strip more cleanly from the casting, and they can usually be made more cheaply. Loam is often used for cores made with a strickle-board, or partly with a strickle and partly with a core-box. It is also often employed for very large cores, its strength being usually greater than that of core-sand. Oil-sand cores have come into much favour during the last ten years. These cores are very strong, so that much less reinforcement is required, and are very free-venting, which simplifies production. Chill cores are not much used. Their object is to produce, on the castings, surfaces which are clean, smooth and hard against wear. The bores of small loose rollers may be made

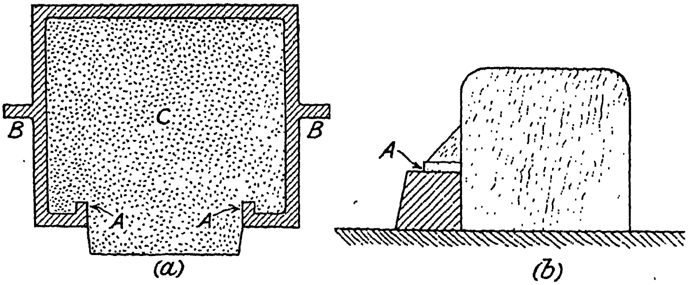


FIG. 10.—(*a*) SHOWING USE OF CORES IN FORMING INACCESSIBLE PARTS OF A MOULD; (*b*) USE OF CORE PRINT TO FACILITATE RAMMING

in this manner, using a mild steel bar, turned to suitable size, and with a very slight taper. Before inserting in the mould, this is given a coating of oil and plumbago, and, as soon as the casting solidifies, the bar is driven out.

Core-Boxes. The variety of core-boxes is legion, depending upon the design of the casting, and the methods employed by the pattern maker. When small cores are required in fairly large quantities, production can be increased by using a multiple core-box, as in Fig. 18 (*a*), which has only to be clamped together once, to make 4, 6 or an even greater number of cores. Pin-boards, as in Fig. 13, are used to make circular cores, in sizes from about 18 in. to 3 ft. in diameter, of which only one or two are required. Their application is not necessarily limited to the production of plain round cores for ribs or brackets can be set in, as desired. Large cores can sometimes be made more economically by this method an example being described later. Large circular cores are usually made with a strickle-board, used in conjunction with a steel spindle and centre bearing, and these are described in detail in the section dealing with core-making in loam.

Patterns leaving Own Cores. Where possible, patterns should be so designed as to enable cores to be dispensed with, *i.e.*, they should form their own cores. Although one commonly refers to patterns as leaving their own cores, when the part in question has been formed by the pattern in the mould, it is not usually described as a core, but often as a *cod.* This may seem a little confusing, but it is obviously necessary to follow foundry custom in such matters. Many ingenious devices are frequently utilised in machine and plate moulding, in order to do without cores, but in general foundries this problem demands greater consideration than it usually receives. Although patterns which leave their own cores need more careful handling, they possess many advantages. The core, which may be of greensand, can be produced more rapidly when it is rammed up in the pattern, for it does not require the substantial reinforcement necessary when a separate core-box is used. The metal thickness is more accurate and uniform. Better venting must be obtained when the core is an integral part of the mould, than when a corresponding loose core is inserted. The time taken to make the pattern is often less than is required to make a block pattern and core-box, and there is also a substantial saving in timber.

Core-Irons. For small plain cores, only a straight wrought iron or mild steel rod is necessary. For supporting small intricate cores, much wrought iron may be used, its softness and malleability rendering it more suitable than mild steel for bending to shape. For large cores, a more rigid reinforcement is required than is afforded by wrought iron, cast iron core-irons or core grids being employed. In large general foundries, where much core-making is involved, a permanent bed is laid down, either by levelling two metal straight-edges, and securing the ends of these on metal plates or weights ; or by setting level in the floor a cast-iron frame, about 6 in. deep and of the required dimensions. Because of its neater appearance, the second method is preferable, and, if the frame is left about 2 in. above the floor level, there is little likelihood of anyone stepping accidentally into it. To prepare the bed, the sand is dug out to the necessary depth, 18 in. or so, this being then filled up with sand in layers about 6 in. deep, by riddling through a ½-in. sieve, each layer being compacted by treading lightly and evenly over. The process is continued until about four inches from the top, which is filled with riddled sand, and scraped off with a straight-edge ; leaving the sand standing about ¼ or ⅜ in. above the frame. This small excess is now bedded down by tapping each end of the straight-edge, in turn, along the frame. Reinforcing the ends of the straight-edge with ⅛-in. mild steel plates, set flush with the face, will lengthen its life considerably. The inside shape of the core-box is now set out on the bed. This can be done by placing the box on the bed, and marking round the inside, by the use of a template or paper pattern, or by measuring with a rule and straight-edge. The grid pattern is stamped out in the sand by means of a dabber, made either of wood or iron, a wooden one being shown in Fig. 12 (*f*).

To prevent the core-iron from resisting the contraction of the casting in cooling, so as possibly to lead to fracture, a clearance must be left between the core-iron and core-box. The amount necessary is governed by the length and width of the iron, and the wall thickness of the casting. For a core-box 12 in. across, $\frac{3}{4}$ in. clearance should be sufficient. In a core 4 feet long, at least 2 in. clearance should be allowed. If the same core is only 12 in. wide, however, the 2 in. clearance is only required at the end, $\frac{3}{4}$ in. being sufficient along the sides. Large core-irons should be fingered, *i.e.*, should have a number of prongs all round their edges, when there is less resistance to the contracting casting, the sand round the edges tending, when under compression, to slide along the fingers as the casting contracts. (To avoid any risk of fracture, however, it may be necessary to take out the core-irons as soon as the metal has set, this precaution being essential for large thin castings, with their great contraction and low strength.) After the grid has been stamped out on the bed, iron prodder-bars of suitable lengths are pushed into the sand, to provide the prongs for the reinforcement of the various parts of the core, the lifting staples are inserted, and the mould is ready for casting. A typical core-iron casting, with cast-in prodders, is seen in Fig. 14. To prevent the staples pulling out of the iron when lifting, those of smaller size are nicked with a cold-set or chisel at the end, before casting-in, while larger ones may either be turned outwards at the end, or veed.

Sizes of Lifting Staples. For cores of dimensions approximately 12 by 12 by 12 in., one $\frac{1}{4}$-in. staple will be sufficient. A rectangular core, 3 by 1 by 1 foot, will require two of these. If the dimensions are about 3 by 3 by 1 foot, $\frac{5}{8}$-in. material should be used for the staples, and three will give a better lift. For large cores, one must consider t[illegible]en-sand of the staples in relation to the weight lifted. [illegible]d, and yard of core may be taken as weighing one ton, [illegible]than weight of the core-irons in it. The weight of the[illegible] determined roughly from the amount of metal use[illegible] them. Alternatively, the weight of a cubic foot of c[illegible]t be be taken as $\frac{3}{4}$ cwt., plus the weight of its irons. [illegible]small method is probably more simple, and quicker, a[illegible] vent experience, one can estimate the weight of sand in a large core almost at a glance ; certainly with a minimum of mental arithmetic. Where any miscalculation of strength has been made, it is usually not of the strength of the staples, but of the transverse strength of the iron into which they are cast. The core-iron must thus be sufficiently strong round the staple and, if this has been ensured, the following figures can be used with safety :

Staples for Lifting Cores

Diameter of Material forming staples	Weight of core, in tons	Number of staples
½ in.	1·0	3
¾ in.	3·5	3
⅞ in.	5·0	3
1 in.	7·0	3

On a job of large area which springs badly, four staples of equivalent size would be preferable, but, in lifting such heavy cores, one must make sure that the load is not taken diagonally across the core, this being more readily avoided by the use of special adjusting chains or hooks.

Core Plates. These are used for carrying cores, and are essential when the core is in a green state. After drying it can generally be handled without one. Light cast iron or mild steel plates are used for small cores. They must be quite flat and as light as possible, so long as they are sufficiently strong and rigid. Medium-sized and large core plates are of cast iron, of such thickness as not to bend when core is lifted about on them. Cast iron plates are made will [illegible] open-sand bed, as described under the making core-[illegible]. The shape is marked out, and also that of placing lugs, and sifted floor sand is built up round the by [illegible] little above the thickness of the plate, by using with [illegible], blocks of wood, or bricks, set round to the out [illegible] on the bed. A rapid method of forming the or [illegible] is to use two bricks, set on edge, placing between To[illegible] thin strips of wood, as in Fig. 11 (*a*). After the sand has been made up round the bricks, the wooden distance pieces are withdrawn, and the bricks, being thus freed, can readily be removed. Open-sand plates are run through a pouring basin made up close to the edge of the plate, as in Fig. 11 (*b*). A is a well to take the first splash of metal, thus forming a cushion for the remainder. The sand should be very firm at B, or it may wash away. Under A, the sand should first be well softened and then consolidated with the fist. There must be no constriction between the points CC, and it is better to make the mouth wider than the well.

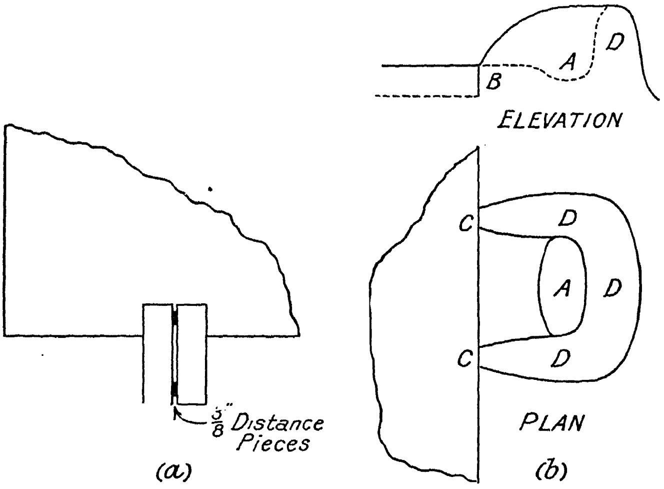


Fig. 11.—(*a*) Rapid Method of Moulding Open-Sand Lifting Lugs; (*b*) Pouring Basin for Open-Sand Plates

When the plate weighs several tons, a few loam bricks should be placed under A, and iron weights DDD built into the outside walls of sand, to prevent the runner bush from bursting. For the runner-basins of large open-sand plates, the floor sand should be well mixed and sieved, and the moisture content must be kept low—a little drier than greensand facing—if trouble is to be avoided.

Venting Materials. In most cores, provision must be made for the rapid removal of air and gases. In small straight cores, this is accomplished by making an open vent down the middle. This hole is produced, either by ramming the sand round a steel rod, known as a vent wire, when the core is being made, or by pushing the rod through the middle, after ramming has been completed. Small intricate cores are vented by laying in the sand a pliable brown wax taper, with a thin cotton core, and sold as "wax vent." The wax melts and runs into the sand on drying, a clear hole being left. Cinders or clinkers, with the fines rejected, are used to vent large cores, and a trench of fine cinders should lead into any small pockets in the core-box. Wax vent, or a piece of straw rope, may also be used to lead from these pockets to the cinders in the centre core.

Blacking. This is used to coat cores and moulds, when its insulating effect not only protects the sand grains from fusion, but also prevents the metal from penetrating into the pore spaces, so that the castings strip cleanly from the sand. Blacking is applied to greensand work in the dry state, either by dusting or brushing on. For dry-sand work, it is first mixed with thin clay-water into a thick paste, and then diluted with more clay-water, until it reaches the consistency of thick paint. Core-gum or other substitute is added during the preliminary mixing, in the proportion of about one handful to a bucketful of the finished blacking. The mixture is applied—either before or after drying, as required—by means of a sprayer, brush or swab. If the blacking cracks or flakes off in drying, the bond is too strong, and the proportions of core-gum and clay must be reduced. If the blacking is powdery, and liable to rub off when dry, the bond is too weak, and the core-gum and clay should be increased. Drying for any prolonged period of time at a high temperature, 300° C. or over, will destroy the bond and make the blacking powdery. So-called "patent" blackings are composed largely of fixed carbon, which may vary, however, between 70 and 90 per cent. of the whole. A good substitute for carbon blacking is foundry furnace coke, if well ground and passed through a very fine sieve.

Plumbago. This, which should be nearly pure graphite, is of a peculiarly greasy and adhesive nature, and, even when dry, sticks readily to the faces of greensand moulds. When pure, it is almost infusible, and it thus makes an excellent mould dressing, but it costs about three times as much as patent blackings. It is used extensively, however, for mixing with these, for dry-sand moulds and cores, to improve the stripping qualities. Inferior grades of plumbago are often much adulterated with cheaper varieties of carbon, however, leading to results which are inferior in this respect. Plumbago is not so suitable for non-ferrous castings, where the surface colour is important, because it leads to a darkening of the skin. If the castings are sand-blasted, or treated with an acid bath, however—when the original surface colour is immaterial—plumbago is frequently used.

Talc, Steatite, Soapstone, French Chalk, Terra-Flake, etc. Where non-ferrous castings are not to be sand-blasted or pickled, a facing of white talc or similar material is employed. Talc is a hydrated silicate of magnesium, which crystallises in foliated or lamellar masses, and is greasy or soapy to the touch. Steatite, soapstone, or French chalk are massive varieties of the same compound, having an earthy fracture. Terra-Flake is a proprietary mixture of the same. These are all used extensively for coating moulds and cores for non-ferrous castings; they are universally employed for aluminium, and occasionally for cast iron; where, for example, in a light casting, the use of a white facing enables one to see much better down a narrow part of the mould than if a black one were used. For greensand moulds, the powder is dusted on and the surplus blown off; while, for cores and moulds which are to be dried, it is used in the form of a wash. For non-ferrous work, a mixture of half and half of talc and plumbago is sometimes used, the plumbago giving a better strip, and the talc a better colour, this compromise being satisfactory for various types of work.

THE MANUFACTURE OF CORES

The core-maker uses comparatively few tools, these generally comprising a moulder's trowel, a heart-and-square, one or two cleaners, a few fillet tools, a corner sleeker and various blacking brushes and swabs, some representative types being seen in Fig. 12. The brushes are sometimes part of the shop equipment, which also includes rammers in a variety of shapes and sizes, vent-wires, shovels, sieves and so forth. The uses of greensand cores have already been discussed. Except that they require more support and usually more venting, the method of manufacture is the same as for dry-sand cores, and no special description need be given.

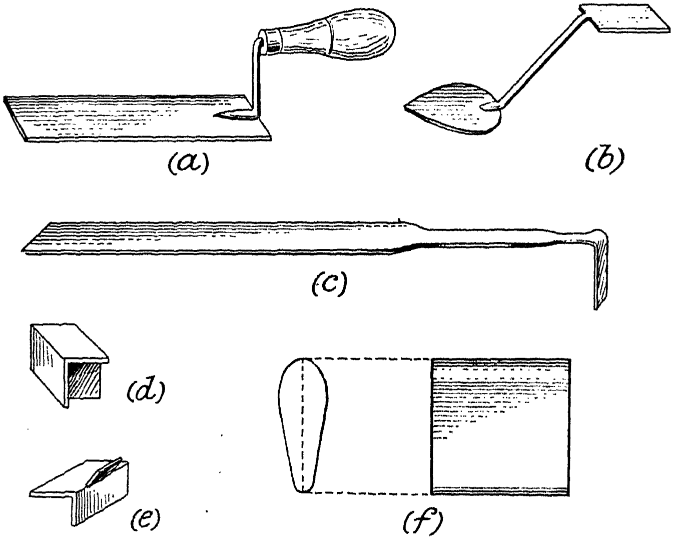


Fig. 12.—Types of Coremaker's and Moulder's Tools. (a) Trowel; (b) Heart and Square; (c) Cleaner; (d) Corner Sleeker; (e) Top-Edge Sleeker; (f) Wooden Dabber for forming Core Irons

Dry-Sand Cores. Small cores need no supports, and, although they do not always require venting, a vent wire is often pushed down the middle. The hole so formed is frequently used for spiking or securing the core in position in the mould. For a rectangular core, if the size does not exceed that of a cube about 9 in. in the side, the necessary support would be afforded by two $\frac{3}{8}$-in. rods laid diagonally across in the sand about 1 in. from the bottom, and two similar ones at the top, with a lifting eye, for lowering the core into the mould, or for bolting it up into the cope, as the case may

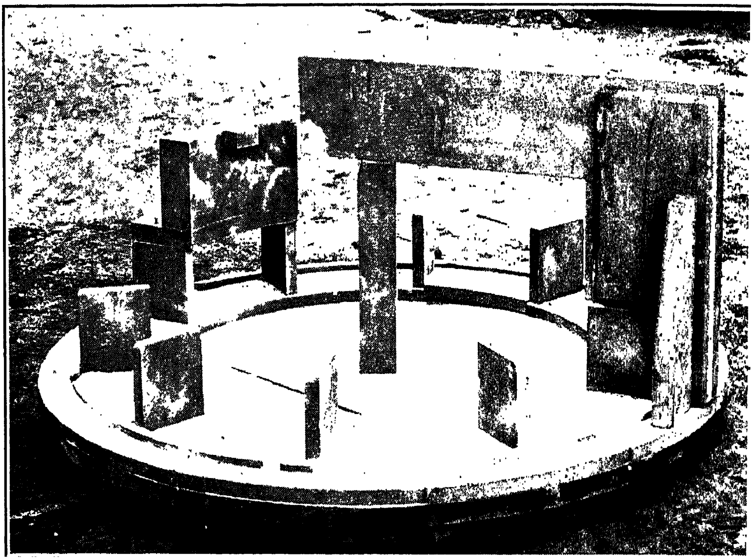


FIG. 13.—PIN BOARD USED FOR LOAM CORE

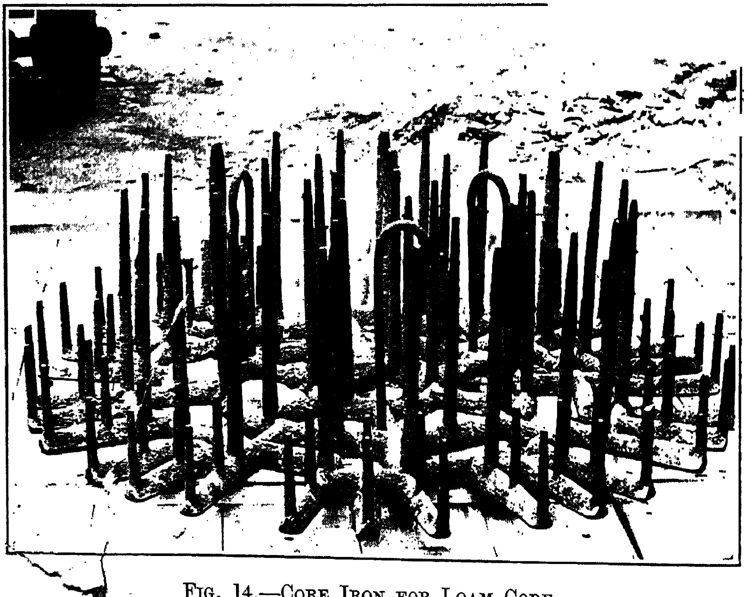


FIG. 14.—CORE IRON FOR LOAM CORE

be. If the core is to be surrounded by metal, the sand walls should be only about $1\frac{1}{2}$ in. thick, the middle being filled with cinders, with the vent led off to the print. The permeability of the sand will be further improved by venting the bottom and side walls before the cinders are rammed in.

Loam Cores. The manufacture of a simple type of loam core is that for a small pipe, which would be made in halves. A piece of wrought iron is bent to the inside shape of the half pattern, and weighted down on to a flat plate. A strickle-board is used to strike off the loam (which has been suitably reinforced) and give the half core its correct shape. By turning over the template, and repeating the cycle of operations, the opposite-hand half core is made. When dried, the two halves are dressed together, a vent passage is scraped down the middle of each of the flat joint faces, and the halves are jointed with clay-wash and thin loam, and bound together, in three or four places along their lengths, by means of a $\frac{1}{16}$-in. steel wire, let into the dried loam, and afterwards covered over to prevent the metal from coming into contact with it. After receiving the usual coating of black-wash, and drying, the core is ready for use.

Loam Core from a Pin-Board. Fig. 13 shows a fairly large pin-board for making a loam core. Although the cost of timber and pattern-making is a little greater than that for making the usual loam-moulding strickle, the extra expense is more than recovered in the foundry, by the saving of the time spent in setting up a loose spindle and board, and spacing out the ribs and location register. The second expense can only be saved when the ribs can be attached in some way to the base of the pin-board. In making this core, parting sand is sprinkled on to the bottom of the board, which is then covered with about $\frac{3}{4}$ in. of reasonably stiff loam, and the core-iron, shown in Fig. 14, is clay-washed and bedded down on the loam. Small pieces of loam brick are clay-washed and built in between the prodder-bars, and the outside wall and the wall round the centre-pin are built up with soft loam and loam bricks. The space in between the two walls is now packed, to within about 2 in.

of the top, with cinders or clinkers, and these are covered with soft loam and loam bricks. A coating of loam is now rubbed over the face of the core, strickled off with the board and allowed to become stiff, after which a coating of very soft sifted loam is splashed over the surface, and struck off with the reverse edge of the board. After standing until the loam bricks have absorbed enough moisture from the loam to enable the core to be lifted with safety from the base board, the loose pieces are removed, and the core is dried and finished off ready for the mould. The completed core is shown in Fig. 15. It will be necessary to describe the manufacture of one or two special cores later, and the production of a large loam core is also dealt with, in a section covering the making of a complete loam mould.

Barrel Cores. The cores for cylindrical castings, as straight pipes, liners, etc., are made on cast iron or steel barrels, those for small pipes, up to about 8 or 10 in. in diameter, consisting of lengths of steel gas or steam piping, having small holes drilled along them. For larger sizes, there is greater difficulty in rotating the barrels, and a special type, shown in Fig. 16 (*a*), made of cast iron, is used, one end being squared to take a keyed handle for turning purposes. The holes at the end afford a passage for gases, which pass through the small holes in the side, into the interior of the core, when this is surrounded by metal. Fig. 16 (*b*) is an end view of the barrel, seated at each end in notched bearings in a pair of trestles. A striking board, B, having a profiled edge, C, is laid along the barrel, and set back to a distance approximating to the core thickness. The barrel is rotated, and rope of straw, hay or wood wool, about $\frac{3}{4}$ in. in diameter, is wound closely along its length, the finishing end being secured by packing under the adjoining strand, fixing, if necessary, by means of a moulder's brad. Soft weak clay is rubbed all over the surface of the rope, and a piece of wood or iron is pushed hard on to the winding, while the barrel is rotated, so as to scrape off any surplus clay, and make a fairly solid base, of diameter such as to leave, between the rope and the striking board, a gap of about $\frac{1}{2}$ to $\frac{3}{4}$ in. While the barrel is rotated, soft loam is fed over the profiled edge

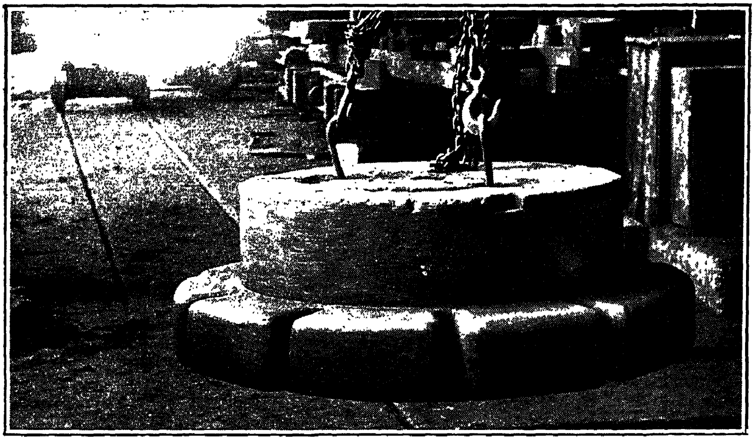


Fig. 15.—The Completed Loam Core

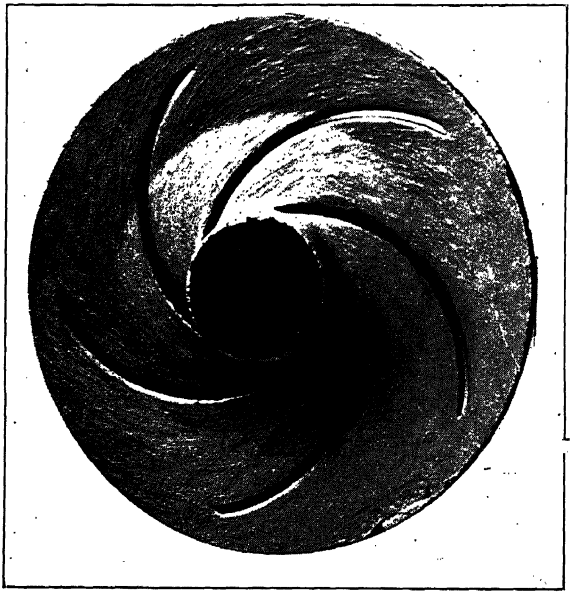


Fig. 17.—Oil-Sand Core for Impeller of Centrifugal Pump

of the board, and adheres to the clay surface, giving a smooth finish. The core is now measured for size, using calipers. If incorrect, the board is adjusted, and a final treatment is given, when the core is ready for drying.

If a core barrel of suitable size is not available, a smaller one can be used, making up with extra layers of straw rope. If much too small, cast iron rings can be wedged at intervals along it, as in Fig. 16 (*c*), and these will prevent the core from sagging or becoming loose on the barrel when shrinkage

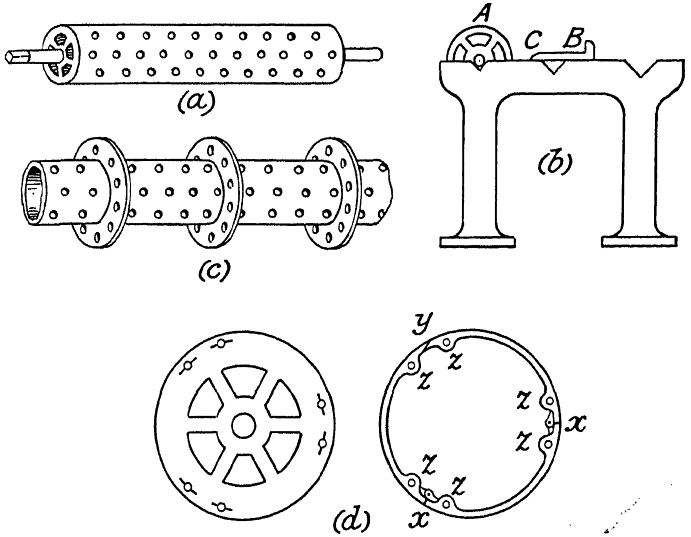


FIG. 16.—(*a*) CAST IRON CORE BARREL; (*b*) ARRANGEMENT OF CORE BARREL AND STRICKLE BOARD ON TRESTLES; (*c*) USE OF IRON RINGS TO INCREASE DIAMETER OF CORE BARREL; (*d*) COLLAPSIBLE CORE BARREL

occurs on drying. Barrel cores are not only of the parallel type shown, but may taper from one end to the other, or be of any shape desired, so long as the section is circular. To minimise the quantity of straw-rope, and the time taken in manufacture and drying, shaped barrels with contours following those of the inside shapes of the castings should be used where the cores are required in quantities sufficient to justify the expense. It is essential that there should be a progressive increase in the diameter from one end of the barrel to the other, or one could not remove it from the casting without damage. When considerable quantities of straight pipes, of large or medium size, have to be cast horizontally, production costs can be greatly reduced by the use of collapsible core barrels, as in Fig. 16 (*d*). These are divided lengthwise into three pieces, hinged together at *xx*, while the third joint, at *y*, is so cut that one portion readily falls inwards. Lugs, shown at *z*, are cast on to the ends, to take cotter pins securing the cast iron end plates, which have short centre spindles of steel, for rotating the barrel. No straw rope is used on the core, and the ¾ in. of loam quickly dries. When the metal has solidified, the pins are knocked out, the end plates taken off, and the barrel is caused to collapse into the bottom of the pipe.

Oil-Sand Cores. These have come into considerable use during the last fifteen or twenty years, and are made from silica sands bonded with linseed oil and molasses, or some equivalent proprietary binder. Silica sand mixtures with straight oils possess little or no green bond, while those made from compounds, sold as "semi-solids," have excellent green bond, this being sometimes still further improved by the addition of some 10-15 per cent. of a sand with natural bond. The proprietary core creams usually give a green bond intermediate between those of the straight oils and the "semi-solids." Oil-sand cores not only facilitate production, but can be constructed with comparative ease, where the design is so intricate that it would be difficult, if not impossible, to make it successfully in the usual manner. Oil-sand cores can be produced far more rapidly than naturally bonded cores. Their relatively high strength when dried reduces and may entirely eliminate the need for reinforcement, while their high permeability renders unnecessary the elaborate methods of venting which must otherwise be used. Cost is probably the only factor which retards their more extended application in general work. Fig. 17 shows an oil-sand core for the impeller of a centrifugal pump, where the provisions both for supporting and venting the core are very simple. Two loose irons of ⅛-in. diameter are laid between each of the adjoining pairs of blades, and two pieces of ⅛-in. wax vent are similarly used, the vent leading to the periphery, which is print. In casting, this core is covered almost immediately, over a large proportion of its surface, with liquid metal, and the gas and air must therefore be enabled to escape in the shortest time possible, or the mould may blow violently, with unhappy results for the casting; hence the need for high permeability, which is a characteristic of oil-sand cores.

Mixtures with straight core oil are most suitable for plain and shallow work. The sand flows readily and one need only press it into the core-box with the fingers, while the mixture can be rammed or vibrated on a machine with ease. The lack of green bond renders plain oils unsuitable for intricate work, except where quantity production will compensate for the cost of special metal cradles, into which the cores are turned from the core-box, to preserve the shape during transit to the stove, and in drying. The cost of making such a cradle is not warranted unless large quantities of one size of core are required, when their use may be advantageous for quite simple cores. An example is seen in Fig. 18, of small round cores made in a multiple core-box. The top diagram (*a*), shows an end view of four cores in the bottom half core-box. The cradle is now placed on top, and the whole turned over. On removing the core-box, the cores are left standing in the cradle, as at (*b*). This cradle may sometimes form the upper half of the core-box, the lower half, of wood, being removed before stoving. The latter method is

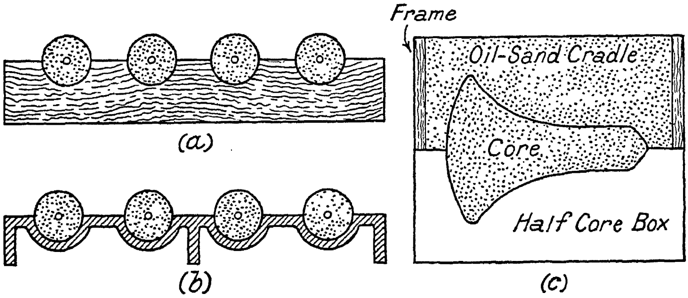
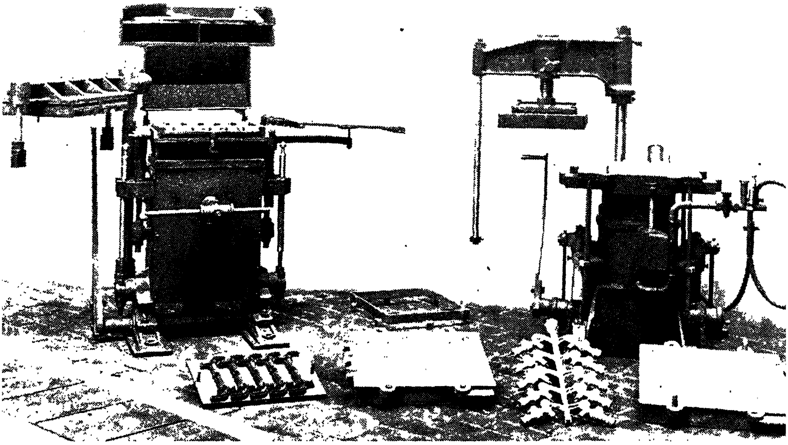


FIG. 18.—(*a*) AND (*b*) USE OF METAL CRADLE FOR SUPPORTING OIL-SAND CORES; (*c*) METHOD OF FORMING SPECIAL OIL-SAND CRADLE

most suitable when only a small number of a particular core are required each day. When the number to be made does not warrant the cost of metal cradles, small ones can be constructed with a good oil-sand mixture, the correct shape being produced by carefully ramming the sand—supported in a suitable wooden frame—round the core, after the top half of the box has been removed, this method being shown in Fig. 18 (*c*). If these oil-sand cradles are used with care and stored when not in use, they will last a long time, but the cores they support should only be subjected to comparatively low drying temperatures before removal from their cradles, or the bond in the cradles may be destroyed by the repeated heatings. If a few only are required, the cradle may be of floor sand instead of oil-sand, the same method being used, but a new cradle must be made for each core.

Core-Making Machines. A variety of core-making machines are now available, but their field is much more restricted than with moulding machines. Core-making by machine is more difficult than moulding by this method, and the development of oil-sand has much simplified hand production, thus rendering machines less necessary. They are often used, however, for special purposes. Straight lengths of round core are commonly made on hand-operated machines, and small cores are sometimes produced by jar-ramming, a vibrating table, on which the box is placed for ramming, being fitted in the middle of the core-bench. Jar-ramming can also be successfully applied for making large plain cores, if there are no projections inside the box to interfere with the flow of sand. Again, small cores, as those required for pipes, bends and tees, can be made quite well on squeezer machines, operated by hydraulic or pneumatic pressure. Core-making by machine is naturally closely related to machine moulding, and moulding machines can often be readily adapted to the production of cores. Fig. 19 shows (left-hand side) a machine of pneumatic-squeezer type, designed for the production of large quantities of small shallow cores, for which the box can be split on a flat plane. A multiple former or core-box is used, a plate of finished cores being shown in the foreground of this figure.



[*Badische Maschinen*

FIG. 19 (LEFT-HAND SIDE).—D.A.K.N. SQUEEZER CORE-MAKING MACHINE

[*To fa*

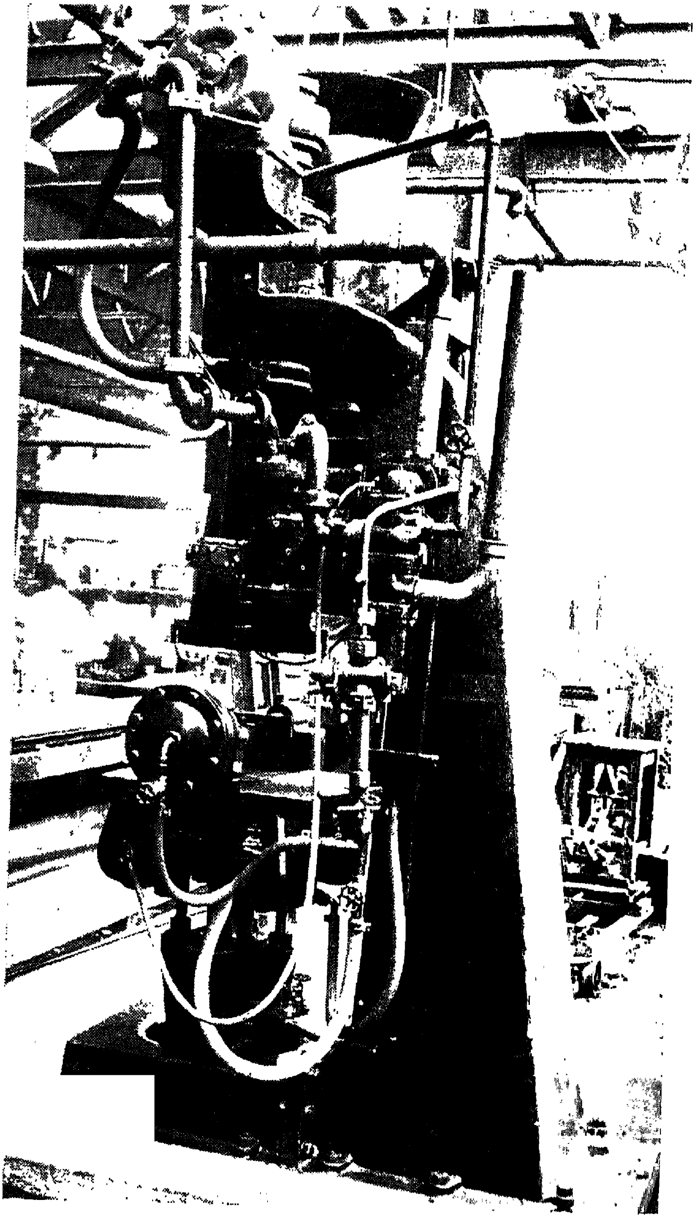


FIG. 20.—THE AUGUST-BORMANN CORE-BLOWING MACHINE

Core-Blowing Machines. The production of small cores has recently been revolutionised by utilising the principle of blowing the sand into the core-box. Successful use of this method demands a large output, and about 2,000 may be regarded as an approximate minimum number to warrant the setting-up of a core-box on this type of machine. There are many different makes available, but these may be divided into two main classes: Those in which sand, mixed with compressed air, is blown into the core-box, and those specially designed to prevent the entry of air with the sand. One of the first type is shown in Fig. 20, the operation of this machine being as follows. Sand is released from the storage hopper sufficient to fill the container, and the core-box is placed on the table, with the opening, through which it is intended to force the sand, registering under the hole in the container. By operating a lever, the table lifts the core-box up against the blowing slide, also bringing into operation the horizontal clamps, so that the core-box is securely held in all directions. The movement of a second lever actuates the blowing slide, so that the sand is at once compressed into the core-box. On reversing the levers the box is released ready for stripping. The complete cycle of operations is very rapid, taking only a fraction of a minute. In order both to obtain still more rapid production and to increase the time during which the machine is actually in use, two or more similar core-boxes are generally employed, the number depending upon the time required to strip the rammed core from the box. One or more operators are thus employed in stripping the cores from their boxes, these being returned immediately to the machine operator for re-ramming.

Fig. 21 shows a machine of the second type, designed to prevent the compressed air from coming into actual contact with the sand, when the wear of core-boxes is materially lessened, while the sand is also maintained in a better condition for use. In using this machine, the core-box is clamped into position, and a hollow cylinder, carrying a piston, is forced through the prepared sand in the container and brought to rest against the opening in the core-box. Air is then admitted behind the piston, and the cartridge of sand in the cylinder is forced into the box. In the machine illustrated, the cartridge contains 10 lb. of sand. Should more than this amount be required to fill the core-box, the operation is repeated until the box is full. Although production by these methods is still somewhat limited, a wide variety of different types of core can now be made. Efficient working of these machines demands the use of a sand having a relatively low green bond. Thus, either drying cradles must be used, or the cores must be bedded out in floor sand, if sagging and distortion are to be avoided.

The Securing of Cores in Moulds. Sand cores have a specific gravity less than one-third that of molten iron, and, unless fixed securely in position in the moulds, tend to rise to the surface of the metal in casting. When a core stands in the drag-half mould, and runs right through to the cope, no provision should be necessary for holding it in position. The moulder should make sure that the cope bears on it sufficiently hard to hold it securely, but not so hard as to break it. Small cores, only a few inches long, can usually be sprigged or spiked in position, one or more holes being made in the core, for this purpose, before it is dried. For slightly larger cores, a staple or hook is rammed into the core, so that it may be secured by twisted wire or a hook-bolt. When large cores have to be bolted into position, if the core-iron is not of such shape as to be near the surface of the core at the place of contact with the mould, staples of suitable strength are cast in, when the core can be fixed as shown in Fig. 22. When a number of small castings have

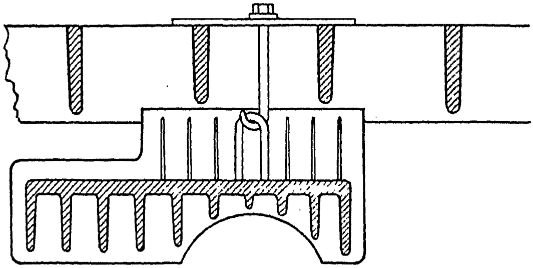
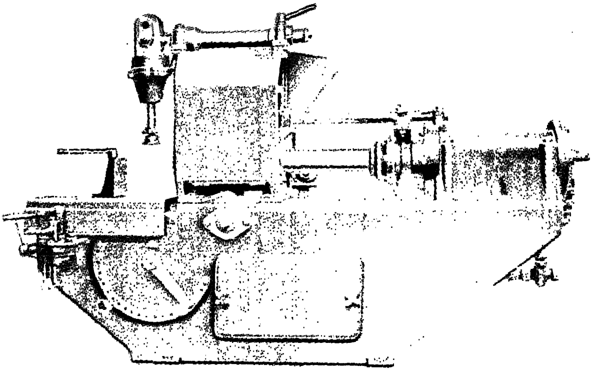


FIG. 22.—USE OF CAST-IN STAPLE AND HOOK-BOLT FOR SECURING CORE TO COPE



IG. 21.—Core-blowing Machine by the Coleman Foundry Equipment Co., Ltd.

to be made, the construction of a twin-pattern and core-box will often overcome the difficulty of holding the core, a typical arrangement being seen in Fig. 23 (*a*). The pattern and core-box are split on the half-joint, shown dotted, and allowance is made at *A* for a fairly wide common core-print, to hold the core firmly in position, and avoid the necessity of the top and bottom supports at *bb*, which must be provided if the pattern is made as a single unit. This device can often be used with advantage when mounting patterns for machine moulding. Small pipe bends, for example, can be made in this manner, when the half core-box must be made to form a full half-core for both pipes, this method of mounting being represented in Fig. 23 (*b*).

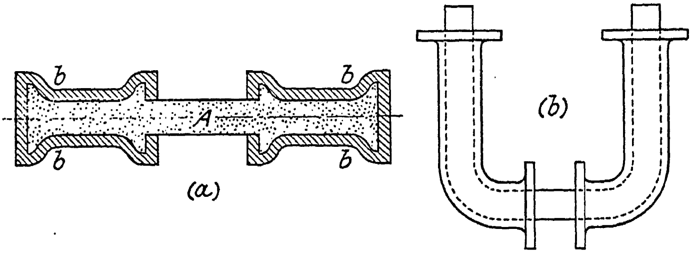


FIG. 23.—(*a*) USE OF TWIN-CORE FOR SECURING IN POSITION; (*b*) TWIN-CORE FOR SMALL PIPE BENDS

Core Registers. The fixing of cores in moulds naturally involves the question of correct location. All standard patterns should be so made that the cores register in their prints only in one position. Circular cores are often located by the use of a flat register, as at (*a*) in Fig. 24. If the position has to be determined even more accurately, a veed register, as at (*b*) in the same figure, is preferable, as not permitting so much movement as a flat one, if the core happens to be slightly slack in the print. When only a half core-box is supplied, with a register in it, the register should, wherever possible, be made common to both halves of the pattern, avoiding any possibility of mistake, or of the loose piece being lost. This is illustrated in Fig. 25, where the register A is required to set the machining ring under the bosses BB. When the core is being lowered into the mould, the print is sometimes out of sight, when the usual register—although often put on by the pattern-maker—is of little use. Fig. 24 (*c*) shows a pattern which has, running along the outside, two strips, BB, required to be at right angles with the internal strips, AA, shown dotted in the core. A register put on to the print at C cannot be seen when the core is being lowered into the mould. The difficulty of setting can be overcome by the use, on the outside of the pattern, of a small V, about ¼ in. wide and 1½ in. deep, with a corresponding one in the core-box, as shown at DD. This results in an addition to the casting not shown by the drawing, but the protuberance is usually not unsightly, and can be allowed to remain on. If necessary, however, it can be removed with a hammer and chisel in two or three minutes.

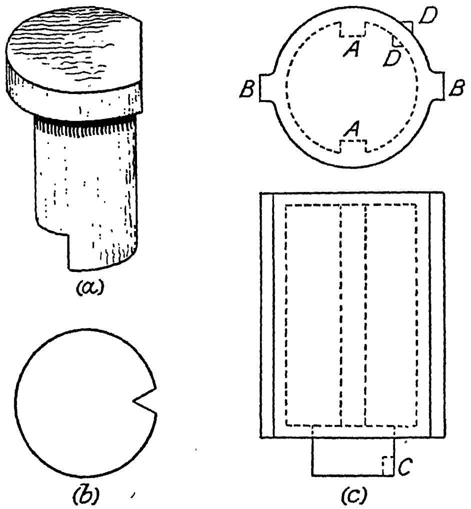


FIG. 24.—(*a*) FLAT REGISTER FOR LOCATING CORE; (*b*) VEED REGISTER; (*c*) SPECIAL METHOD OF LOCATING CORE

Core Venting. The greater the proportion of surface area of the core which is exposed to the metal, the larger the volume of gas generated in casting. There is also more organic matter in cores than in moulds, with a correspondingly greater evolution of gas. Cores thus require more venting and generally more thorough drying than moulds. The necessary freedom of venting is obtained in large cores by filling the interior with clinkers, cinders, or small coke, providing a channel of sufficient cross-section, and filled with the same material, to conduct the gases, *via* a suitable core-print, to atmosphere. The space to be occupied by the filling material must not be allowed to approach too closely to the core face, or this may crack, allowing the metal to flow into the interior. For small cores, not less than 1 in. will be quite safe, but, for very large ones, the minimum distance should be about 2½ in. The permeability of the sand walls

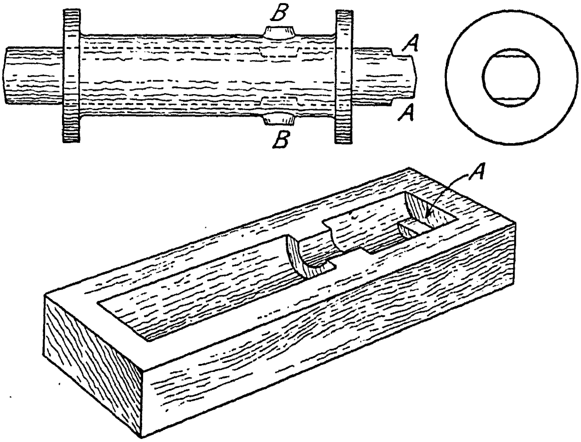


FIG. 25.—SHOWING REGISTERS ON PATTERN AND CORE-BOX

is assisted by the free use of a vent wire, which is pushed into the walls from the interior space before the filling material is rammed in, the mode of operation being indicated in Fig. 26 (*a*). With oil-sand cores, this precaution is hardly necessary, the filling of the interior with clinkers being quite satisfactory, while, for small cores, filling with floor sand is usually sufficient. Long narrow cores are vented merely by pushing a wire through the centre from end to end. Thicker cores made with natural sands require more venting, supplied by ramming up a peg in the middle, and then venting from this hole to the outside of the core, as in Fig. 26 (*b*). Small cores which are thin and intricate can be vented by laying wax-vent in the sand during the ramming operation. The method of venting an impeller core has been described on p. 40.

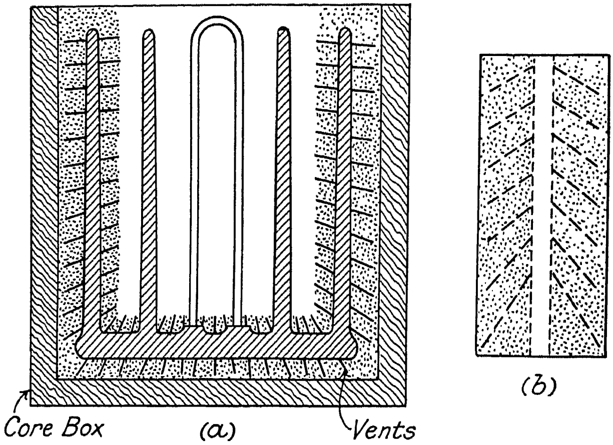


FIG. 26.—(*a*) SHOWING METHOD OF VENTING; (*b*) AUXILIARY VENTS IN HEAVY RECTANGULAR CORE

Core Drying. Successful core production depends on thorough drying. In this process, there is a permanent growth, the amount varying directly with the temperature of stoving. If the initial temperature is too high, distortion may also occur. Stoving at low temperature tends to preserve both the size and shape of the core more accurately. Small cores should be dried thoroughly, and tested by holding a piece of cold steel over the vent exhaust when the core is hot. If moisture tends to condense on the steel, the core must be returned to the stove for further drying. If, however, the core has only one face in contact with the metal, thorough drying is not so essential, because the directions in which gases can escape from the mould face are much less restricted. Where the work is of a repetitive nature, drying can be done more systematically, by stoving for a given time at a definite temperature, avoiding the use of cold steel and other empirical methods. One should dry as near as possible to the maximum temperature that can be maintained without prejudice to the essential qualities of the mould or core, and for as short as possible a period, so long as the drying is sufficient. In practice, the limits must be determined by the method of trial and error. Large cores are seldom dried completely, and steam can often be seen coming from the cinders, *via* the vents, after the core has had its final stoving. Moisture left in the cinders is not objectionable. In no circumstances, however, must the sand constituting the outside walls contain any moisture.

Drying Temperatures. Since the principles governing successful drying are practically identical for both moulds and cores, it will be convenient to make this portion of the chapter apply to both. Damage by overheating may be brought about in more than one way. Preliminary heating at too rapid a rate will cause the sand to crack, especially with loam. If the temperature is too high after the free water has been dried out, some of the combined water may be driven off from the clay, the material becoming " burnt " and crumbly. A temperature of 250° C. is a good maximum for small and medium work made from natural sands. For large work, a maximum of 300° C. may be allowed, if the temperature is not allowed to remain too long at this figure. Since straw, manure, etc., begins to burn at a little above 300° C., it is not advisable to exceed this figure in any circumstances. Oil begins to char a little above 280° C., and core-gums a little below this temperature, so that oil-sand cores must be dried more gently, at about 200° C. as a good average figure. All stoves should be fitted with recording pyrometers, and a good current of hot air circulated through the chamber.

Design of Stoves. The design and size of the stoves depend naturally upon the class of work. Where quantity production of small cores is required, a very satisfactory arrangement consists of a battery of small ovens, heated from a common fire-box, as in Fig. 27. Here the products of combustion enter the compartments by the flues AAA, and exhaust by the flues BBB, the temperature of each stove being readily controlled by means of adjustable covers on the inlet and exhaust flues. A reasonably high chimney is required to obtain the necessary draught. If it is desirable for any reason to use a low stack, forced draught can be employed, using a small fan blowing into a sealed ash-pit at C. Portable drying carriages can very conveniently be utilised with this type of stove. The carriage, of steel, is of such size as nearly to fill the compartment, and stands on four short legs. It is moved in and out of the stove on a low truck, so designed as just to pass under the lower frame of the carriage. By depressing a lever actuating four cams, the top frame of the truck is raised, so as to lift the carriage from the ground for transport. This arrangement allows the drying carriage to stand close to the core-bench, where it can be loaded direct as the cores are finished, a large number of unnecessary journeys being eliminated. A new type of stove for dealing with small cores is shown in Fig. 28. The double casing of sheet metal is packed with a 3-inch layer of insulating material. Through the middle of the front side passes a vertical shaft carrying four circular trays, which can be independently rotated through 180°, an insulated panel, running across their centres, constituting the front of the stove. In use, one half of each tray is in the drying chamber, and the other outside, so that it can gradually be loaded with cores as they are made. The combustion

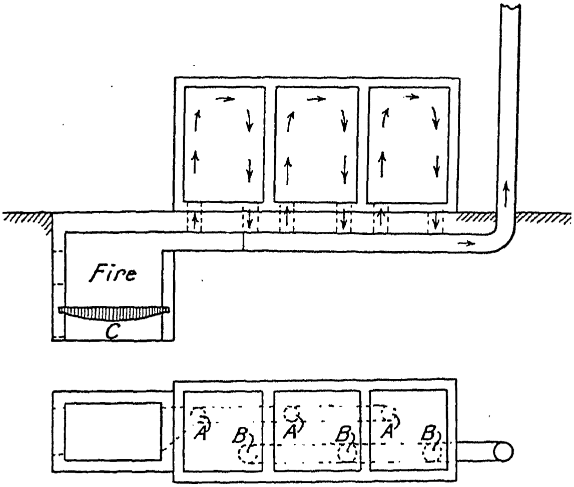
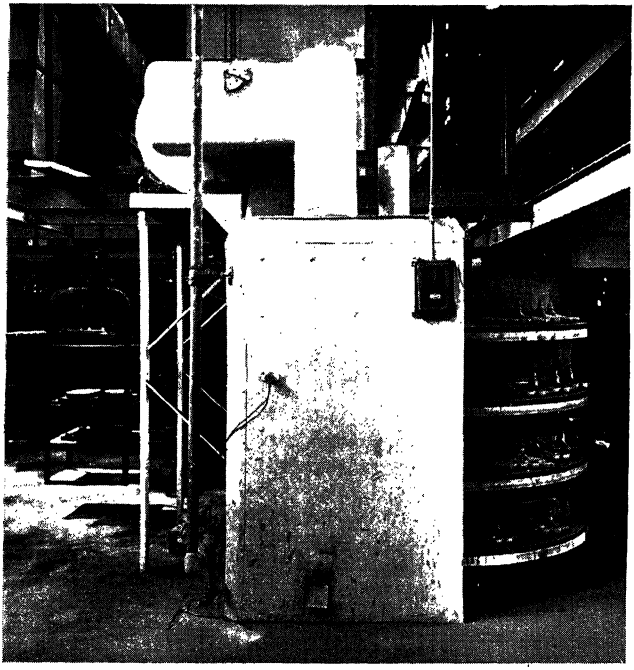


FIG. 27.—OVENS FOR DRYING SMALL CORES



IG. 28.—Core-Drying Stove by Controlled Heat and Air, Ltd.

[*To face p.* 50

chamber can be fired either by fuel oil or gas, with a thermostatic control from the oven temperature, the drying being effected by hot air circulation.

The old method of drying large cores and moulds, with one or more open fires inside the drying chamber, is still in extensive use to-day. Providing one arranges, in the floor of the chamber, suitable exhaust flues to connect with a high chimney, reasonable efficiency, both as regards fuel consumption, and speed of drying, can be obtained. It must be admitted, however, that, when open fires are thus used, one seldom finds that the exhaust conditions and the circulation of air inside the chamber are very satisfactory, and there is no doubt that many of the modern drying systems give more economical, and, what is more important, more reliable drying. The usual arrangement is to have, outside the drying room, some form of firebrick combustion chamber, when, by blowing air into a sealed ash-pit, the products of combustion are forced from the fire-box into the stove, where they circulate freely as they pass to the exhaust flues. Some system of admitting secondary air to the fire-box is usually employed to complete the combustion of the carbon in the fuel. The superiority of the modern stove is very largely due to the use of forced draught, for, when natural draught is relied on, unless a particularly high stack is used, too great an interval elapses before the chamber reaches the maximum temperature. It is undesirable to make the drying chamber too high, and, unless the type of work makes it absolutely necessary, 12 feet should not be exceeded. Drying is also less satisfactory when the area is large, and it is suggested that, if efficiency is of prime importance, the maximum area for a stove 12 feet high is about 400 sq. ft. The area may naturally be greater if the height is reduced. In a comparatively novel method of heating large core and mould stoves, developed by Messrs. Mirrlees, Bickerton and Day, Ltd., there is an underground coal-fired combustion chamber, fed by a mechanical stoker, the fuel feed being thermostatically controlled by the temperature of the latter, so that a high efficiency is obtained.

Continuous Stoves. The earlier continuous drying stoves were horizontal, and, although giving excellent service, occupied much valuable floor space. Those installed to-day are almost always of vertical type, an arrangement which not only enables one to dry a very much greater number of cores for the same floor space, but also allows of a much readier removal of the products of combustion and the fumes from the cores being dried. The Acme Vertical Stove deals with a very large number of small cores by the continuous method. The Junior model, shown in Fig. 29, is one of the smallest types made, and deals with a quantity varying from 150 to 300 sq. ft. of core plates per hour, depending of course on the volume of sand in the cores. The furnace is contained in the main bodywork and three distinct drying cycles are obtained, the first consisting of a rapid heating by the products of combustion, the second of an oxidising and final drying by injected air ; while the third is a cooling stage, during which air is circulated over the cores.

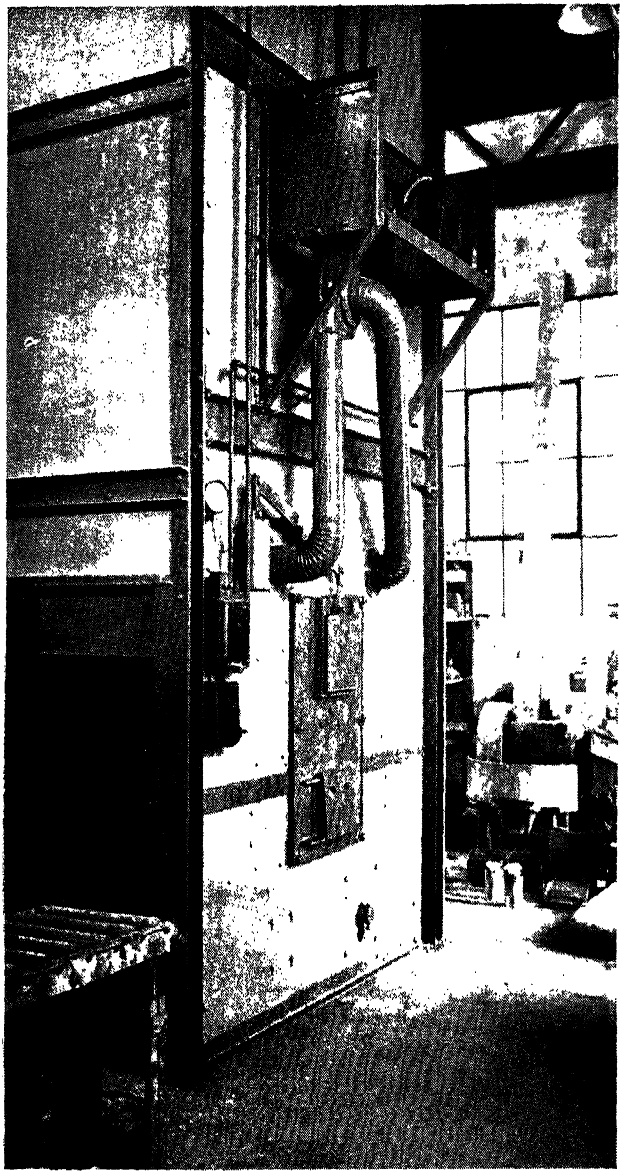
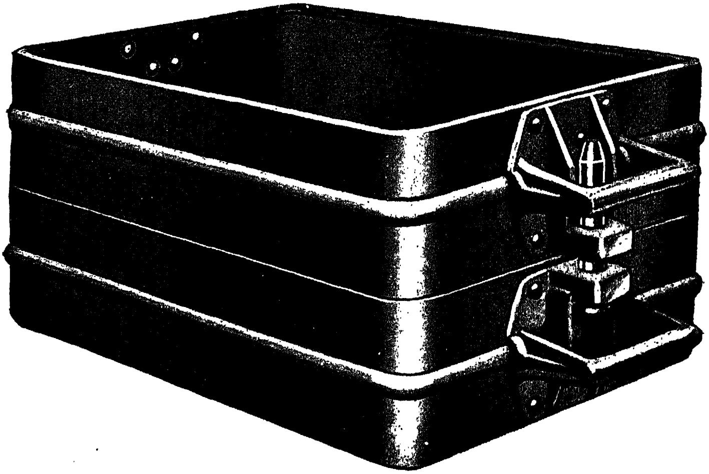


Fig. 29.—Small Continuous Vertical Core-Drying Stove, by the Foundry and Engineering Co., Ltd.



[*Sterling Foundry Specialities, Ltd.*

FIG. 30.—TWO-PART MOULDING BOX, MADE OF ROLLED STEEL

CHAPTER III

MOULDING TACKLE

For rapidity and economy in production, the design of moulding boxes and the arrangement of moulding tackle requires careful consideration.

Moulding Boxes. These are used to hold and support the sand after the pattern has been withdrawn, and in casting. The design should be such that the sand is held without risk of its falling-out, and that there is a safe minimum of sand round the pattern. The box must be so rigid that it will not distort. It must be cheap in relation to its life. It must be light and yet durable. Each box of a series must be interchangeable. These qualities are not all best found in the same material, and a variety of these are employed, cast iron being generally favoured. Wooden boxes have been much used in America, where wood is cheap, finding some application in Great Britain, as for aluminium. In foundries casting only light alloys, aluminium boxes are sometimes employed. In recent years, pressed steel boxes, particularly for the smaller sizes, have come into favour.

Boxes are usually square or rectangular in shape, a two-part box, made of rolled steel, and exceedingly light and rigid, being shown in Fig. 30. Steel is less satisfactory for the larger sizes, when cast iron is used, a design as in Fig. 31 being often adopted. The drag or bottom half carries flat bars to resist the downward pressure of the metal, and the cope or top half has bars placed on edge, to support the sand when the box is lifted about, and to prevent the pressure of the metal from pushing the sand up through the middle of the box. Where possible, the shape of the box should have a definite relationship to that of the casting, this reducing the time taken in ramming, and the amount of sand per casting. If large quantities of circular castings are to be made, as tractor wheels and similar work, circular boxes should be used.

Moulding boxes are often made to build up in tiers, to take patterns of varying depth, enabling a wider range of castings to be made with the same capital expenditure on box parts. The larger sizes will give better service if made from loose parts, *i.e.*, two ends and two sides bolted together as in Fig. 32, when the stresses set up in casting can be much reduced. If this type of box is used for jar-ramming, one must have at least two fitting bolts or two large dowels at each corner, to prevent any slip at the joints during jarring. The cope presents a different problem. The pattern is often contained entirely in the bottom half, the cope being merely a shallow cover, as in Fig. 47. Copes have to be lifted and turned over repeatedly, drag halves rarely. Extra handling necessitates better rigidity so that the rammed sand may be retained securely during these operations; and it is difficult to obtain rigidity in a built-up part which is shallow. The cope should therefore be cast in one piece, with the cross-bars integral with it.

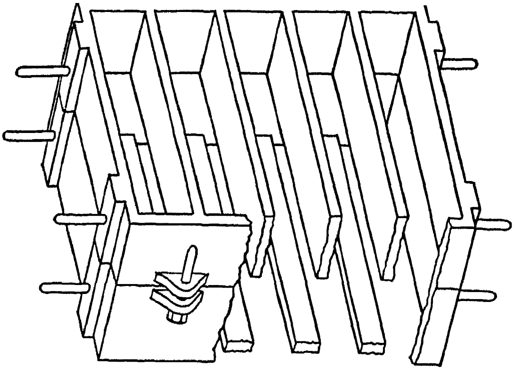
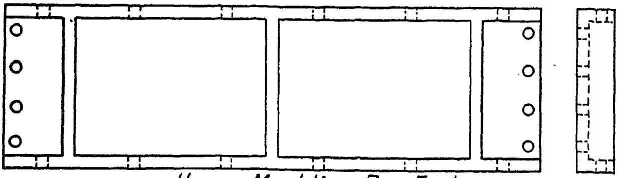
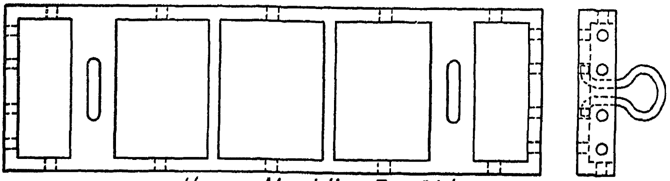


FIG. 31.—PAIR OF CAST IRON BOX PARTS, SHOWING ARRANGEMENT OF BARS

When a deep cope is required, as when it contains half of the pattern, one may have to build it up as in Fig. 32, bolting in separate bars. If shallow copes are used, and the length is great compared with the width, the weight may cause the part to whip or bend excessively on lifting, if it is made all in one piece. Or, the weight of the cope when rammed may exceed the crane's lifting capacity. In either case, the cope must be made of two or more parts, end to end, which can be handled separately. When the cope is thus divided, disadvantages result. Extra locating pins or stakes are essential, and a double number of lifts are required. Where the two top parts butt together, additional flash is produced at the joint, necessitating more trimming. The advantage of simplicity in cope construction is thus obvious. For the outside frame, one generally uses a heavier section than for the crossbars, so as to be stronger, while the parts crossing over the pattern are made narrow, when the sand flows under them more readily. This variation in size, and consequent difference in rate of cooling, may lead to distortion in a large cope, unless precautions are taken. The best method is to split two diagonally opposed corners, fitting in a distance piece, and bolting them together, as shown in Fig. 33, at A.



Heavy Moulding Box End.



Heavy Moulding Box Side.

Fig. 32.—Parts of Large Moulding Box

Methods of Location. Except with patterns having a flat upper surface, one must employ some means of locating the cope correctly, after the pattern has been withdrawn for closing. For small boxes, it is best to use steel pins, as fitted to the parts in Fig. 30. These are turned to be a driving fit in the drag-half holes, the upper part of the pin, which passes through the lugs in the cope, being turned two or three thousandths of an inch below the size of the holes drilled in these. Boxes up to, say, 6 feet square, should have the pin-holes accurately drilled and reamered to a plate jig, ensuring interchangeability. The jig-drilling of boxes is not always done for general work, but is essential in machine and plate moulding. Driving the pins permanently into the drags is used only on small boxes, the larger sizes being usually drilled to take a loose shoulder pin. A convenient method is to use a $\frac{3}{4}$-in. easy fit in the drag, the cope holes

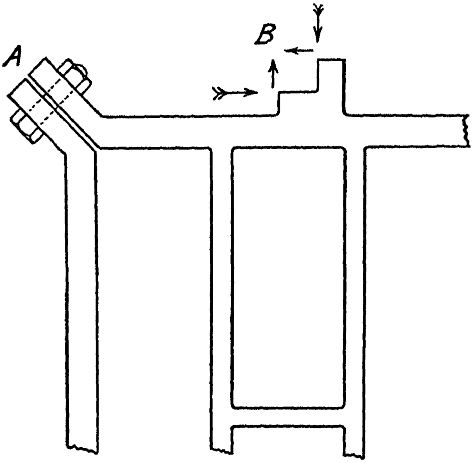


FIG. 33.—METHOD OF RELIEVING CASTING STRAIN, SHOWN AT A; AND ANGLE STAKING PIECE USED ON LARGE COPES, SHOWN AT B

being 1 in., and the upper part of the pin three to five thousandths less in diameter than this. Loose pins are sometimes used for locating, when the bearing surface on the pins must be increased, if accurate registration is required. This can be effected by having the pin passing through four lugs, side play being thus prevented. In a method of locating used on pressed steel boxes, one pin is round, with about two-thousandths of an inch clearance, the opposite hole being elongated or slotted, while still maintaining accurate lateral fit. If the patterns are bedded in the floor, the cope cannot be registered by guide pins, when it is usual to make the top part with four angle pieces near the corners. Iron or steel stakes are driven into the ground at these corners, a wooden wedge or iron weight being driven in behind each, to hold it firmly. If the cope is flat, or has only a shallow lift, with plenty of taper, registering is simple, for the stakes can have a good inclination outwards, when the cope leaves and returns to the same position with certainty. When the cope has a deep straight lift, more care is necessary in staking, and one can use the method indicated in Fig. 33 at B. On viewing the stakes alternately from the direction of each of the double arrows, each should lean very slightly outwards at the top, in the direction of the single arrows. There need then be no difficulty; but moulders accustomed to working with complete boxes are often quite at sea on this job. For machine-moulding, the pin-holes should be tight-fitting, and must be drilled out and bushed as soon as any wear occurs. For loose pattern work, where the cope is always rammed on the drag, these refinements are unnecessary, and registration can be obtained by twisting the cope clockwise on the drag before ramming, twisting it similarly when locating finally for casting. If there is much clearance in the pin-holes, however, besides twisting clockwise, one should whiten over the box joints in several places, and scribe several lines across the joint, before parting the half-moulds.

Bolting, Cottering and Clamping. Small boxes are often held down for casting by loading with iron weights, but the use of clamps is preferable. These are made from $\frac{3}{8}$-in. steel plate, the slightly taper jaws being a little wider at the open end than the distance over the two box lugs, on to which they are lightly tapped before casting. For somewhat larger boxes, the location pins may be slotted to take cotter pins. Still larger boxes are drilled along the flanges, and bolted together, as in Fig. 32. Heavy steel or cast iron clamps may be used, but are not so satisfactory.

Jigs and Drilling. To ensure that boxes shall be interchangeable and half-mould parts shall assemble correctly, machine- and plate-moulding boxes must be drilled by means of flat frame jigs, with the pin-holes accurately spaced, and fitted with case-hardened steel bushes. Jig-drilling is also desirable for small and medium-sized boxes for loose patterns, much reducing the proportion of cross-jointed castings. Any other holes required in the box flanges should also be spaced out by the jig plate. For very large boxes, used only for loose work, the production and storage of large jigs is too costly in comparison with the advantages obtained. If one cope part of each size, however, is carefully marked out before drilling, and always used as a template for drilling the other boxes of the same series, interchangeability will be maintained, but larger pin clearances must be given.

Snap-flasks. These are special boxes, in which the moulds are rammed, but not cast, so that a single pair of boxes can be used for any number of moulds, with economy in capital expenditure and storage space. The boxes are hinged at one corner, the opposed diagonal corner being fitted with a clasp, which is released after the mould is closed, the flask being thus detached from the sand forming the mould. The two half-moulds are usually held together for casting by a flat weight, with a hole through which the metal is poured into the down gate. Because the molten metal also exerts a lateral pressure increasing with head pressure, only shallow work can so be made. When making slightly deeper work, or when the pattern is near at any point to the sides of the flask—contingencies which might lead to the bursting of the mould in casting—the mould must be reinforced by steel frames, set in the snap-flask before filling with sand, collapse being thus precluded.

Lifters or Gaggers, and Straight Irons. Lifters are L-shaped pieces of cast or wrought iron, usually provided with a small additional turn at the upper end. They are used for supporting the sand in copes to obtain a better lift from the pattern, the upper turn being made so that this end can more readily be hooked on to the box bar. They are also used for various other kinds of sand reinforcement. Lifters are stocked in standard sizes, or made up as required. Material of ¼-in. diameter is suitable for sizes from 3 in. to 6 in. long. If used only for greensand work, those more than 6 in. or so in length will last longer if made of heavier material, $\frac{7}{16}$ or $\frac{1}{2}$ in. square. In dry-sand work, the lifters are often badly bent in knocking out the castings, and, if material $\frac{1}{2}$ in. square is used, straightening becomes costly. For dry-sand purposes, rod of $\frac{3}{8}$ or $\frac{7}{16}$-in. diameter should be suitable, and can be bent cold. Cast iron lifters are made in a reversible chill mould, mounted on trestles and revolving on trunnions, with moulds on both sides. A small hand-shank is used to run one side, the chill being then swung over and the other side cast in turn, so that casting can be continuous. The section of the lifter must be such that it will fall readily out of the chill when turned over. Before beginning to cast, the chills should be coated with wet blacking and dried thoroughly. Lifters of any length up to about 14 or 15 in. long can conveniently be made in this manner; if longer, they tend to break in handling and are less satisfactory. Straight irons are of mild steel, wrought iron or cast iron, varying from $\frac{1}{4}$ to $\frac{3}{4}$ in. in diameter, and of any length. They are used to reinforce moulds and cores, and are laid in the sand when ramming, being usually left about $\frac{1}{2}$ or $\frac{3}{4}$ in. from the face of the pattern, but may sometimes be much nearer. The ends nearest to the pattern are dipped in clay-water before use, to make the sand adhere. Old files and similar pieces of old steel are also used for the same purpose.

Rammers. These ram the sand firmly into the boxes, packing it to an even density all round the pattern. There are several varieties, the most useful being the pin-rammer, which exerts a lateral as well as a downward pressure, facilitating the packing of the sand on the vertical faces. Flat rammers are used for finishing off after pin-ramming. Types of pin- and flat-rammers vary somewhat, according to individual taste. Gagger-rammers are used for ramming in between lifters, in pockets or other places not readily reached by a pin-rammer. A gagger-rammer often consists merely of a piece of $\frac{5}{8}$-in. wrought iron or mild steel, but may be of any desired shape or size. Mechanical rammers, operated by compressed air, are much used in some districts. When a large volume of sand has to be rammed, these reduce fatigue and accelerate production considerably. They are not so applicable to greensand work, where it is less easy to judge the density of ramming when this is being done mechanically. On dry-sand work, where the absence of moisture more than compensates for any reduction in permeability due to hard ramming, they can be most useful. When loam moulds are supported for casting by ramming sand round the outside, pneumatic rammers will expedite this operation materially.

Vent Wires. These, which are employed in size varying from $\frac{1}{16}$ to $\frac{3}{8}$ in. in diameter, are used for making, in the rammed sand, passages for the rapid escape of gas from the mould face, so that " blown " castings may be avoided. The vent wire tends to wear to a sharp point, with a gradual taper running a long way along the wire, so that it becomes hard work to vent to any depth with the larger sizes of wire. They are therefore knobbed at the end, as in Fig. 34 (*e*), when the rest of the wire passes readily through the clearance hole so produced.

Chaplets. These are used chiefly for supporting cores in moulds, constituting distance pieces to hold the core at the correct distance from the mould face. Four different types are illustrated in Fig. 34 (*a*). In casting, the metal flows round the chaplet, and, on solidification, it should be firmly anchored in the casting. Chaplets should only be used when they cannot be dispensed with, the usual types being a prolific cause of trouble, particularly in pressure castings. The chief difficulty is that of leakage round the edges, where the surrounding metal has not united completely with the chaplet. To obtain a good joint, a little of the chaplet surface must become molten. If the metal only chills on the chaplet, air passages will often be left. The joint may be so poor, indeed, that, on breaking up the casting, the chaplet will fall out completely. The upper part of Fig. 35 shows part of a large casting broken across a chaplet, which has fallen out and is seen separately on the right, indicating a very poor joint. At the bottom on the right of the same figure is seen a patent chaplet, designed for pressure work, where the

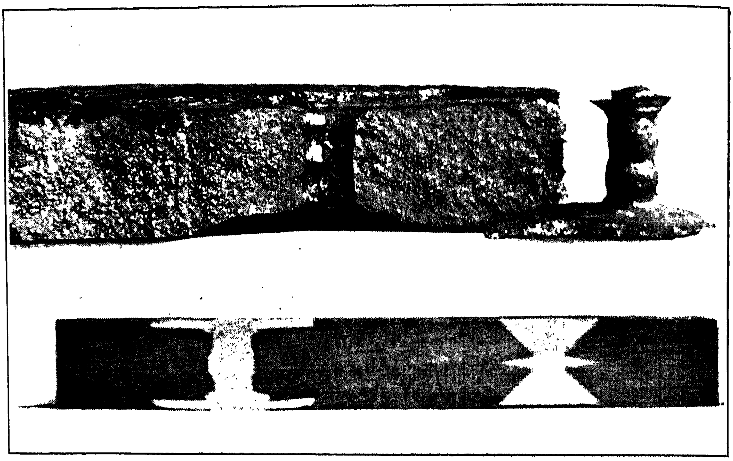


FIG. 35.—CHAPLETS WHICH HAVE BEEN CAST IN

At the top is a chaplet (right), which has come completely out of the casting (left). At the bottom is a chaplet of ordinary type, associated with gas-holes (left), and a patent chaplet, showing a sound joint (right).

tapered central flange fuses readily round its thin outer edge, forming an effective seal against pressure leakage. The bottom left-hand side shows an ordinary chaplet, with one or two gas-holes near to it. Pipe nails, shown at Fig. 34 (*b*), are a type of chaplet with a sharp spike attached, for pushing the required distance into the sand. Pipe chaplets, as at Fig. 34 (*c*), can be obtained, either in the form illustrated, or with short pointed stems, their chief purpose being to support pipe cores in position. Chaplets can be bought in many sizes, to suit almost any requirements. For successful use, they must be clean and free from rust—a fruitful cause of blow-holes in castings. Rust contains water in combination, and a large volume of steam is disengaged when molten iron comes into contact with a comparatively small quantity of it, as seen by the violent ebullition when a rusty feeding-rod is dipped into a ladle of metal. Untreated chaplets cannot be kept from rusting in the foundry atmosphere, and they are therefore bought tinned, when, if stocked in a reasonably dry store, they will keep almost indefinitely. The two types shown at the top right-hand side of Fig. 34 are usually made of cast iron. The metal flowing round them is often at a

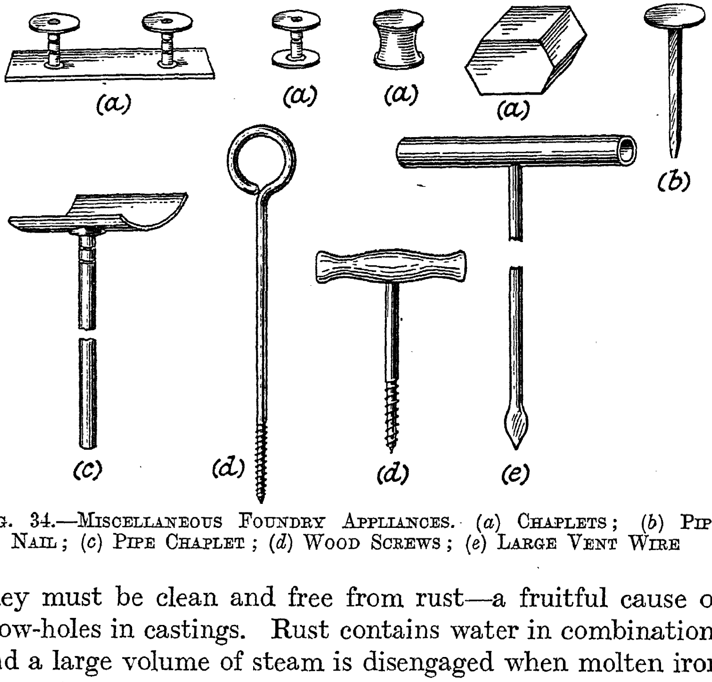


FIG. 34.—MISCELLANEOUS FOUNDRY APPLIANCES. (*a*) CHAPLETS; (*b*) PIPE NAIL; (*c*) PIPE CHAPLET; (*d*) WOOD SCREWS; (*e*) LARGE VENT WIRE

temperature much higher than the melting point of the chaplet, so that this must not be placed in the track of the metal as it flows through the runner gate, or it may be melted completely, thus causing the core to float out of position. Such chaplets should be made of cast iron low in phosphorus, which reduces the melting point. Cast iron chaplets should be cleaned before use, coating them with red lead and turpentine, and drying off.

Miscellaneous Appliances. Moulders' brads or sprigs are a cheap form of nail, roughly stamped from sheet metal, and used for reinforcing parts of moulds or cores. Wood screws are made from fairly large ordinary ones, but often have a mild steel extension, terminating in a ring, welded on to them, as in Fig. 34 (*d*). Shorter ones may be made by casting a knob or bar on to the screw head. They are screwed into the pattern, loose pieces, runner gates, etc., for lifting out of the mould. The moulder's personal tools consist usually of a trowel, a heart-and-square, cleaners, flange tools, calipers, a 2-foot rule, and a large assortment of sleekers for finishing off the variety of shapes found in moulds. Brushes in several sizes are necessary, being sometimes furnished by the employers; in other cases the moulder is expected to supply his own. Wheelbarrows, buckets, watering-cans, sieves, shovels and the like, form part of the shop equipment.

CHAPTER IV

MOULDING TECHNIQUE

Moulding operations, while simple in themselves, constitute in the aggregate an intricate craft, the successful practice of which demands a skill of high order. A knowledge of the various details is clearly essential to an understanding of the making of complicated castings.

Turn-Over Boards. The pattern is laid on a turn-over board to ram the drag half, as in Fig. 36 (*a*). The joint face is placed downwards on the board, and the drag-half box is put on. The pattern is covered thinly with sifted facing sand, the box rammed with floor sand, strickled off flush with the edges, and the whole turned over. Turning over ensures that the sand is uniformly packed round the bottom face of the pattern. To complete the mould (as in Fig. 36 (*b*)), the drag half having been turned over and the board removed, the sand joint round the pattern is smoothed over with a trowel, and dry parting sand is sprinkled on the joint, to prevent the sand in the box part above the joint from adhering to it. Parting sand consists of silica sand, or well-burnt sand with no bond. The cope is placed over the drag, the runner and riser gates fixed in position, and the top is rammed with sand. After withdrawing the gate sticks, the top is lifted off, the pattern is removed, the runner gates are cut, the mould is finished and blacked, and the cope is closed on the drag. The metal entering the pouring basin flows, *via* the runner gate, into the mould, and, when this is full, is forced by the pressure of the column of metal in the runner, up into the riser bush, completing the cast.

Joints. A mould joint is a parting plane in the sand round a rammed mould, to enable the pattern to be withdrawn with a minimum of damage to the sand shape. In making a joint, the sand is rammed hard, the surplus being scraped off with a flat piece of wood. After smoothing with the trowel, parting sand is sprinkled on. Faces which are not flat can be covered by sleeking a thin layer of wet parting sand on them with a trowel. Paper may be used, and gives an excellent parting. Joint partings are usually made as close as possible to the upper face of the pattern, this much simplifying moulding. When ramming up a cube, for example, the joint would be round one of the flat upper surfaces, this being the simplest form of mould joint. For a spherical pattern, the joint must be made round the middle line. Joints are not always flat, and may be of any shape, according to the type of moulding box and design of pattern.

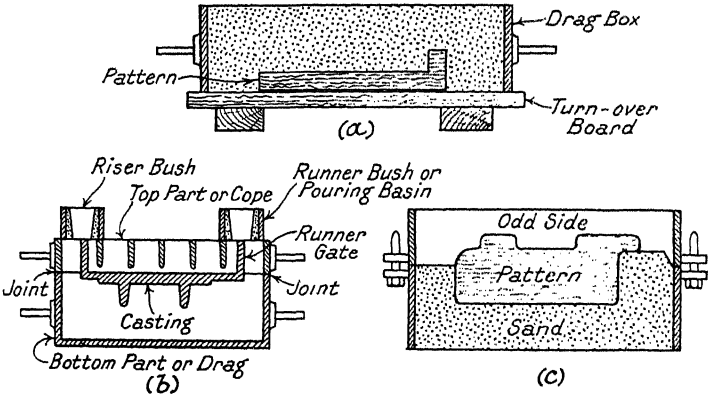


Fig. 36.—(*a*) Use of Turn-Over Board ; (*b*) Closed Mould Ready for Pouring ; (*c*) Method of making Odd-Side

Odd-Sides. An odd-side takes the place of a turn-over board, the simplest form being used for flat backs, *i.e.*, patterns having flat upper surfaces. For these, the cope may be filled with floor sand, flat rammed, and strickled off level with the edge. This gives a flat surface, on which the pattern is laid, joint face down, for ramming the drag, just as when a turn-over board is used. When the joint parting is irregular, and a number of castings are required, a semi-permanent odd-side is used. A dry-sand odd-side will last for a surprisingly long time, if the joint face is treated with a good coating of tar after stoving, to harden it and prevent crumbling. This method has the advantage of facilitating the making of the mould joint, because, when the drag is turned over and the odd-side is removed, the shape of the joint is already formed, and it only needs sleeking with the trowel, and the application of parting sand. An odd-side is made as follows. The position of the parting line is decided, the pattern is rammed in the drag, and the joint made. Fig. 36 (*c*) shows the pattern rammed in the sand, and the cope to hold the finished odd-side in position. After covering the pattern, the cope is now rammed fairly hard with dry-sand facing, lifted off, finished and dried, when it requires only a coat of warm tar, and final drying to finish. The moulding boxes must all be interchangeable, for all the drag boxes must fit the odd-side cope. When large numbers are required, plaster of Paris makes a better odd-side, the surface being smoother and the joint more accurate. In this case, after the joint has been made, fine parting powder is dusted on, and the exposed surface of the pattern is oiled, to stop the plaster sticking. The plaster is added to water to form a thick fluid paste, which is poured over the pattern in the odd-side flask. When set, it is lifted off, and the sand sticking to the joint is removed. When thoroughly dry, it is ready for use. To save plaster and make the odd-side lighter, iron bars can be wedged across inside the flask just above the pattern. The flask need not then be filled, the bars being only just covered with plaster. The use of turn-over boards and odd-sides enables the underside of a pattern to be rammed and vented as easily as the upper side, which is covered by the cope. The limiting size of mould that can be made thus is governed mainly by the crane capacity. When a drag for a 5- or 6-ton casting of shell type is turned over, it may involve the lifting of boxes and sand of over 20 tons in weight, the total weight depending on the superficial area and the thickness of the casting.

Loose Pieces. These are troublesome, but cannot always be avoided. Fig. 37 shows, in the boss *a* at the top, a type of loose piece often found on small patterns. A flat joint is used, and the two screws are taken out of the boss during ramming. After withdrawing the pattern, a long sharp spike is driven down the rib B into the boss, which is then withdrawn. Instead of screws, wooden dowel pins, which are more easily removed, are sometimes used, but may often be accidentally struck by the hammer and broken off flush with the pattern face. To prevent this, one may use $\frac{3}{8}$-in. diameter steel pins, casting an iron knob on to one end, to facilitate removal. Great care is necessary to prevent loose pieces from getting out of position. On standard patterns, particularly for small work, it is better to dovetail the piece on to the pattern so that it will be left in the mould after taking out the pattern. The dovetail must be parallel with the direction of withdrawal of the pattern. If it were desirable that the boss shown in the last figure should be dovetailed, it would be constructed as shown at the bottom of Fig. 37. The pattern being withdrawn in the direction of the arrow, the round facing is left behind. The dovetail should be an easy fit and seat down properly on to the end A, or it may wedge tightly, causing a bad draw. One must also have a continuous taper on the edges and the back side, from A to B. When the intervening aperture is too small to permit the loose piece to be withdrawn, other methods are employed. The loose piece may be taken out while ramming up, as in Fig. 38, where A is too wide to draw

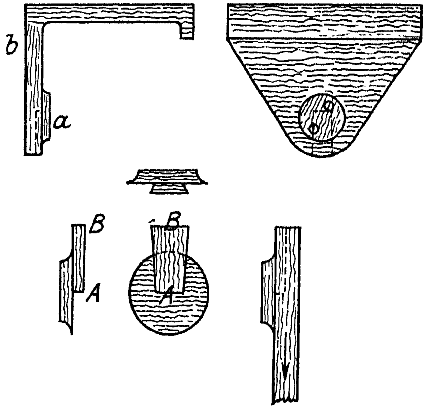


FIG. 37.—BRACKET, WITH LOOSE BOSS, *a*, AT TOP; AND METHOD OF DOVETAILING, AT BOTTOM

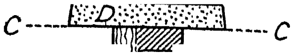


FIG. 38.—CORE COVERING SPACE LEFT BY WITHDRAWAL OF LOOSE PIECE A

into the rib B. When the drag containing the pattern, inverted for ramming on a board, has been rammed up to the line CC, a small joint parting is made, and the loose piece A is taken out A loam cake or flat core D is placed so as to cover the space left by the withdrawal of A, and the ramming of the drag is continued. The core prevents sand from getting into the cavity, and, after removal of the pattern, the space previously left by the removal of the loose piece becomes part of the mould.

Distinguishing Colours on Patterns. Since the locating of loose pieces in the wrong position has often caused spoilt castings, the question of pattern colouring must be considered. Many works use only two colours, black for core prints, the rest of the pattern being red. Sometimes three different colours are employed, for core prints, machined faces and unmachined parts, respectively. Where important castings are being made, particularly when pressure tests are required, the institution of a complete colour scheme for standard patterns is well worth while.

In the British Standard Specification No. 467, of 1932, different schemes are adopted for patterns to be used for iron and steel and for non-ferrous castings, respectively, the recommended colours being as follows :—

		Castings in Iron and Steel	Non-ferrous Castings
Surfaces unfinished		Black	Red
Surfaces machined		Yellow	Yellow
Loose piece seatings and backs ..		Natural wood (varnished)	Natural wood (varnished)
Core Prints	End of core print ..	Red	Black
	Periphery of core print:		
	Unmachined holes ..	Red	Black
	Machined holes ..	Yellow	Yellow
	Core print seats ..	Red	Black
Parts stopped off		Nat. wood (varnished) with black stripes	Nat. wood (varnished) with black stripes
Chill seatings		Not provided for	Not provided for

In the authors' practice, many patterns are used alternatively for both cast iron and gun-metal, so that the use of a different colour scheme for the two classes, the necessity for which is in any case debatable, becomes actually undesirable. Further, this specification makes no provision for a special colouring for chill seatings. This appears essential, because there is often a considerable interval before a pattern comes once more into the foundry, when the results of previous experience—involving the necessity for chilling at certain places before a sound casting can be obtained—may be entirely lost sight of, unless the positions of the various necessary chills have been definitely indicated.

The standard colour scheme used in the authors' practice is compared below with that adopted by the American Joint Committee on Pattern Equipment Standardization:—

Scheme of	Authors	Amer. Joint Comm.
Unmachined parts	Black	✓ Black
Machined parts	Yellow	Red
Loose piece seatings	Black ground, with yellow oblique stripes	Yellow ground, with red oblique stripes
Core prints	Red	Yellow
Parts stopped off	Black ground, with red oblique stripes	Yellow ground, with black diagonal stripes
Chill seatings	Yellow ground, with red oblique stripes	Not provided for

Both schemes apply equally to patterns used either for iron and steel or for non-ferrous castings. It should be said that the authors' scheme was in use before either of the two standard specifications were published. As neither of these provided for chill seatings, and the British specification seemed undesirably complicated, while a temporary confusion is always involved in changing from one system to another, the authors' original scheme is still in use, and has always worked very satisfactorily.

Split Patterns. To facilitate production, suitable patterns may be split on a horizontal plane, and accurately dowelled together. A pattern is often parted on its centre line, as is illustrated in Fig. 39 (*c*). A split pattern simplifies the making of the joint. The removal of the top half of a pattern with the cope avoids the possibility of damage occasioned by lifting the cope off a pattern set partly in the drag, when much patching may be necessary. Where convenient, large patterns should be split as near to the top as possible. General practice, unless the quantity justifies the making of a special cope, is to stock shallow ones. Splitting near the top then saves time in making the joint, reduces the

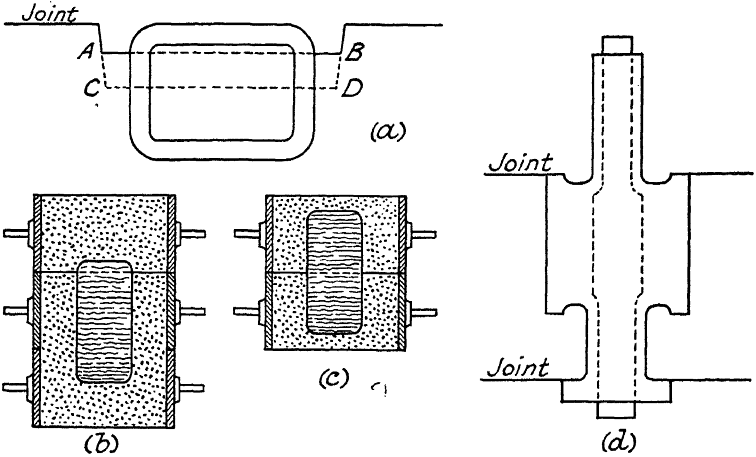


Fig. 39.—(*a*) Different Methods of Splitting a Pattern; (*b*) Small Pattern, split at top, requiring three box parts; (*c*) The same Pattern, split at the middle, requiring only two box parts; (*d*) Armature Hub Casting, requiring two joints

amount of liftering, and—because sand has to be rammed through the cope bars—enables ramming to be done more quickly. Splitting near the top of the pattern, as at A B, instead of C D, in Fig. 39 (*a*), will facilitate production. Small symmetrical patterns can be split on the centre line, because these are moulded in boxes without crossbars, so that a reduction can often be made in the total depth of boxes, and thus in the amount of ramming required. In Fig. 39 (*b*) splitting near the top necessitates three box parts, two only being required if split at the middle, Fig. 39 (*c*). When dowelling together split patterns with a symmetrical joint plane, a pair of large and a pair of small dowels should be used. When the pins are of the same size, they may be fitted almost equidistant from the centre, when the two halves may be fitted in a reversed position, with the joints not quite matching round their edges, *i.e.*, lapped or cross-jointed. Since the top half pattern is placed on the bottom half after this has been rammed in the sand, the reversal may not be obvious, and it may be necessary to feel for it. The use of dowels of different sizes makes incorrect registration impossible.

Three-Part Jobs. Many types of casting necessitate the making of two joints, separating the mould into three parts, this simplifying removal of a bottom part of the pattern which is larger than the middle part. The use of a second joint may be avoided, particularly on large work, by working parts of the pattern loose, or by using cores and drawbacks. Fig. 39 (*d*) shows an armature hub, which, to obtain a sound and clean face, is made coupling end down. It would be difficult to mould this job on end with only one joint, so that, to withdraw the pattern and make the mould accessible for finishing and blacking, two joints were used, as shown.

Stopping-Off. This is more frequently used in jobbing foundries, and involves the employment of a pattern larger than is actually required. After the removal of the pattern, the part not required is filled with sand, or, in foundry parlance, is " stopped-off." This often saves pattern-making, but involves more work in the foundry, and the amount of this must always be considered in relation to the saving on patterns. When the order is likely soon to be repeated, the additional expense of making a new pattern will probably be amply repaid. Fig. 40 (*a*) shows a small bracket with the prints extended to the joint face, when they are known as " tail-prints." After the round cores, shown dotted, have been inserted in the mould, the extension is stopped-off. The method is illustrated in Fig. 40 (*b*) and (*c*), where a flat board, with a half-round hole to fit over the core, is inserted down the rib, and the print A is rammed up with facing sand. Stopping-off the extended portion allows one to utilise short pieces of round core, which are generally in stock. If there were many castings to make, however, it would be better to provide a box to make a core of the shape shown in Fig. 40 (*d*). This would form the round hole in the casting and also fill up the print extension, avoiding the necessity for stopping-off.

Bedding-In. This operation involves the ramming of the bottom half of the mould without having to turn it over as described. In large moulds, the total weight of sand and boxes may be very great, and such castings can be made in this manner with much less crane power. It may be economical

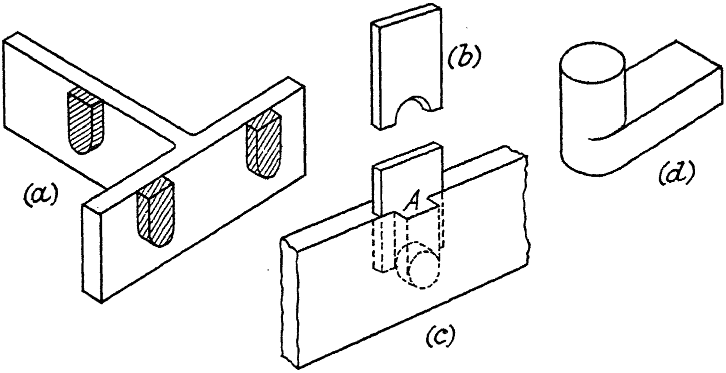


FIG. 40.—(*a*) PATTERN WITH CORE PRINTS (SHADED); (*b*) STOPPING-OFF PIECE; (*c*) STOPPING-OFF PIECE IN POSITION; (*d*) TAIL-PRINT CORE ELIMINATING STOPPING-OFF

to bed-in medium-sized and even small patterns, according to the tackle available and the shape of the pattern. Smaller patterns are bedded in the foundry floor; for larger castings, pits, reinforced with cast iron plates, are provided. When bedding-in small patterns, a hole is dug with 2 or 3 in. clearance all round and underneath the pattern. The bottom of the hole is flat-rammed, to make it quite solid, and enough floor sand is riddled in to bring the top face of the pattern a little above floor level. The pattern is taken off again, a little facing sand is sifted on to the floor sand, the pattern is replaced once more, and then bedded down by tapping until the top is approximately at floor level. The distance the pattern must be tapped down depends upon the amount of soft sand beneath it, and its depth. Shallow plates, etc., must not be made too hard on the bottom face, or the castings may scab. Deeper work must be rammed harder, because the pressure is greater. Thus, the deeper the pattern, the harder must it be tapped down, to compact the sand. When bedding-in medium-sized or large patterns with bottom faces which are flat, or nearly so, the bed is prepared as follows. After the floor of the pit has been rammed solid, one levels up two straight-edges, the upper edges of which are the depth of the pattern below the floor. Floor sand is rammed between these to within 1 in. of the top, this upper layer being rammed carefully with facing sand, which is struck off level by means of a third straight-edge. If the bottom of the pattern is quite flat, it is laid on the bed, and the sides are rammed up. If there are any facings on the bottom, the pattern is put on the bed and tapped down lightly, to imprint the facings slightly. A few small registration stakes are driven in at the corners of the pattern, the pattern is removed, the impressions of the facings are cut down to the depth required, and the pattern is replaced. After tapping down to ensure complete bedding, the sides are rammed up. The venting is discussed on page 122. A method, often used in dry-sand work, can be employed for patterns with irregular bottom faces and not too wide. The bottom of the pit is rammed to within 3 in. of the pattern face. Four bricks, one at each corner, are put under the pattern, which is wedged up level. By weighting the pattern to prevent lifting, facing sand can be rammed underneath to form the bottom shape. This method is quick, but one uses more facing sand, and additional finishing is necessary.

Drawbacks. When patterns are bedded in the floor, there is rarely more than one joint. Many devices are used to avoid a second, one method being the use of drawbacks. These are parts of the mould made independently, reinforced as in the case of cores and similarly capable of being separately lifted from the mould. They may sometimes be removed from the mould before the pattern, to enable this to be withdrawn. Or, the main body of the pattern may first be removed, and the drawback later, to enable a loose part to be withdrawn. They are also used so that parts of the mould can be removed, to make it more accessible for finishing, so that it may more readily be dried and to enable the cores to be more readily assembled in the moulds. Fig. 41 shows a drawback used in a large mould, to enable the pattern to be removed, and to permit the core A to be assembled. The vertical joints should have plenty of taper, when the drawback can be removed without damage. With drawbacks of this type, little or no venting is necessary, for the molten metal makes contact with only a very small part of its surface.

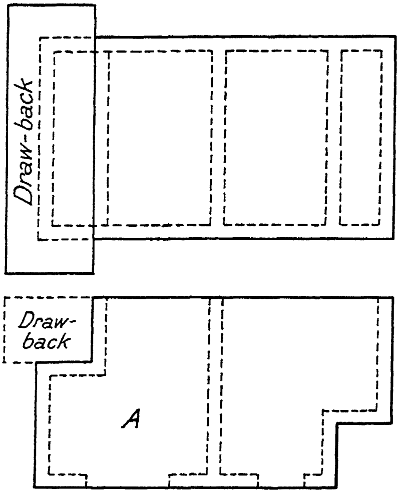


FIG. 41.—USE OF DRAWBACK IN LARGE MOULD

Where a good deal of the surface is exposed to the metal, and especially if metal has to flow over the top surface, the same thorough venting is necessary as for cores.

Finishing, Repairing or Mending Up and Closing. Finishing is that part of production between the removal of the pattern and closing, including all necessary repairs. When making small castings, if the pattern is a good one, no repairs should be necessary, the only finishing being the application of the plumbago or blacking. The faces of small greensand moulds are dusted with plumbago, through a moulder's blacking bag, the surplus being blown off. For larger moulds, which must up of runner and riser bushes, and the weighting or bolting down of the cope. In intricate work, closing is a vital operation, when great care is necessary, if good castings are to be produced.

The Production of Various Types of Casting. Considering now the production of some typical castings, we may take first a small cylinder liner for a Diesel engine. Since this has to be machined all over, and must thus be free from any defects, it is made in dry-sand. Fig. 42 (*a*) shows the split pattern. Since the liner is moulded on the flat and turned on end to cast, each box part has three half holes at one end, for the runner, core vent and riser respectively, Fig. 42 (*b*). A turn-over board is placed on the floor, and half the pattern and the runner-gate stick are laid in position upon it, as in Fig. 42 (*c*). The box has shaped bars which clear the pattern board and runner-gate by about 1 in. Facing sand is sifted on and tucked tightly under the bars with the fingers, a little floor sand being filled in between the box bars along each side of the pattern, and pin-rammed. A piece of plate or a few lifters are put on to each end of the core print, to support the core, and ramming is continued

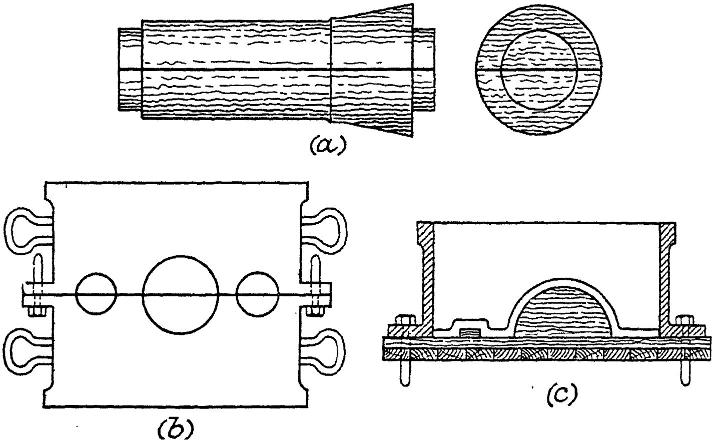


Fig. 42.—Casting of Diesel Engine Liner
(*a*) Split Pattern; (*b*) End of Moulding Box; (*c*) Arrangement of Half-Pattern and Runner Gate

be more refractory, the plumbago is applied with a soft brush, or, better still, with the fingers, the excess being brushed off. A coating even more resistant to the flow of the metal is obtained by rubbing well on, and then sleeking over with a moulder's trowel or other tool. The wet blacking used for coating dry-sand moulds is applied with a swab, brush or mechanical sprayer. One to three coats may be used, depending on the mass of the casting and the pouring temperature. When the casting must have a good finish, the blacking is smoothed over by holding the flat face of the tool at a very slight inclination to the face. One thus avoids what is known as "clagging," *i.e.*, the sticking of the blacking to the tool. The surface is finally washed lightly over with thin gum water, or water blacking, applied with a fine brush. With jobbing patterns, more finishing is necessary, and includes cutting fillets, shaping up defects due to a damaged pattern, and any venting or sprigging done after the pattern has been withdrawn. Nearly all moulds made from loose patterns, except small ones from new patterns, require some mending-up. This is often because old and damaged patterns are being used, but the withdrawal of a perfectly good pattern may disturb parts of the mould face. One may also have a bad "lift" when the cope is removed. The damaged parts must be repaired with facing sand, shaped with the fingers, or by ramming sand in between small loose pieces of wood, used to give the correct form. The surplus can be removed by rubbing with a small rectangular piece of wood or cork, used by all moulders. If only a small guide is visible, one must take off the pattern facings, brackets, bosses, etc., and put them back in the mould before patching can be done correctly. When part of the pattern projects into the cope, a bad lift resulting, the pattern can be put back into the cope for mending-up, this method being often used to ensure that the cope joint shall be of correct shape, matching the corresponding one in the drag. In patching dry-sand work, a limited use may be made of the watering brush, but water should only be used on greensand moulds with extreme caution. Closing covers the assembling of cores and draw-backs in position, the cleaning-out of the mould and the closing of the parts together. It also comprises the making in layers to the top, when surplus sand is scraped off, and one finishes by flat-ramming between the box bars. The board is clamped or bolted to the box-flange, the whole is turned over, and, the turn-over board having been removed, the flat joint is finished off with the trowel. Any sand is brushed off the pattern, the top half of the pattern is fitted, by the dowels, to the bottom half, and the cope half box, which, except that the bars are of opposite hand, is the same as the drag half, is located by the pins over the drag. The cope is rammed up, just as the drag, except that a lifter is put on the joint in each bar close to the pattern, to prevent sand from falling out on closing. The pattern is toggled up into the box by a wood screw, so that the upper half pattern is lifted with the cope, and a good lift is ensured. Both half patterns are lightly loosened and removed, the two moulds are finished, the runner, riser and vent passages are cut, and the half moulds, having been coated with blacking,

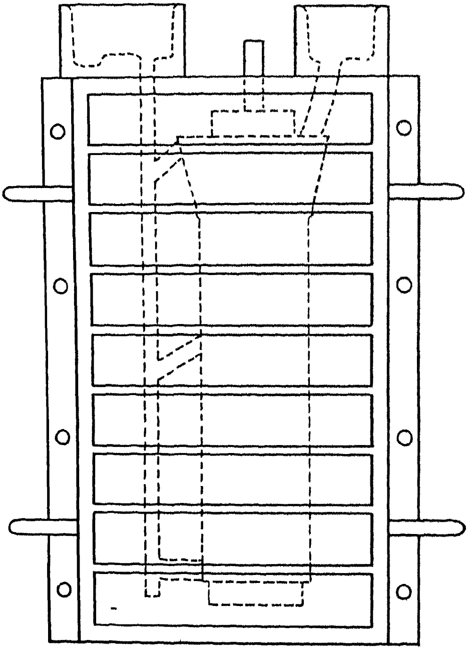


FIG. 43.—MOULD FOR DIESEL ENGINE LINER, CLOSED READY FOR CASTING

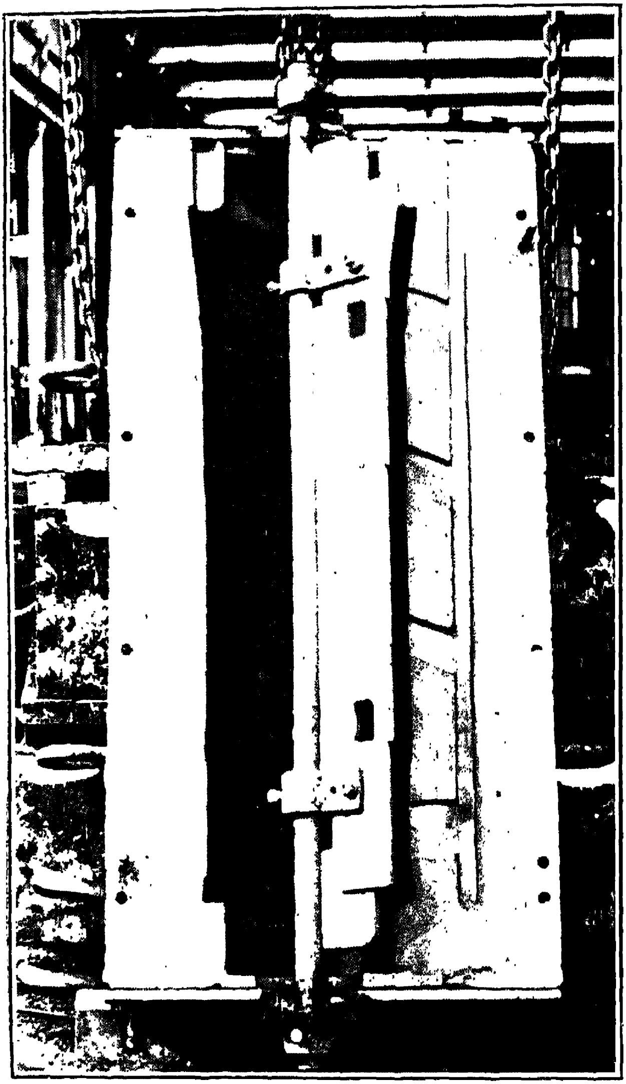


FIG. 44.—ARRANGEMENTS FOR STRICKLING DIESEL ENGINE CYLINDER LINER

To face p. 77]

are ready for drying. After drying, the core is put in position, the cope is closed and bolted to the drag, and the two are turned on end into the casting position. The runner and riser bushes are made up, and a tube is inserted in the core vent, making up round this with sand, to prevent metal from entering. The mould, shown in Fig. 43, is now ready for casting. Very large liners are always moulded in the position in which they are cast. Liners of medium size, in which the diameter approaches the length in size, can nearly always be rammed more quickly on end, when no special boxes are required. The same method may be adopted for small liners, and, if comparatively long and therefore difficult to finish, an extra joint can be made near the bottom, as with the hub in Fig. 39 (*d*). After the pattern has been withdrawn, the lower joint is parted, to enable the mould to be readily finished and blacked. When the box shown in Fig. 43 reaches a total capacity of about 40 cubic feet, so that at least 30 cubic feet of sand must be rammed into it, a varying method can be used with advantage. The mould shape is strickled with a horizontal spindle and strickle board, a complete half mould made thus, with spindle and board in position, being shown in Fig. 44. The tackle comprises two half casings of cast iron, with machined joints and jig-drilled pin-holes, and a detachable half-bearing plate bolted to each end. The plates are set accurately to the pin-holes by using fitting bolts or dowels, ensuring exact registration. The ends of the casings have machined pads finished to a definite length in relation to the locating pins. A steel spindle, fitted with a collar at each end working outside the bearings, carries two short spiders or arms, as shown in Fig. 45, at the top, for securing the profile board, the arrangement being seen in Fig. 44. After the bearings, board and spindle have been set in position, the casing is bricked up, as described under loam moulding, about 1 in. of loam is swept on to the face, A, and 1 in. on to the joint, B, shown in Fig. 45, at bottom. In making the cope half, one must use grids, bolted over the bricks at C, to prevent these from falling out when turning over on to the drag. The chief advantage of this method is that no pattern is necessary, only a board of correct profile being required. After the first liner has been made, one need only replace the 1 in. of burnt loam on the face of the brickwork with new loam. All moulds after the first dry very quickly, and loam gives a clean hard mould, usually producing a better casting than with sand. A disadvantage is the cost of the tackle involved, but this can often be used for other types of cylindrical casting.

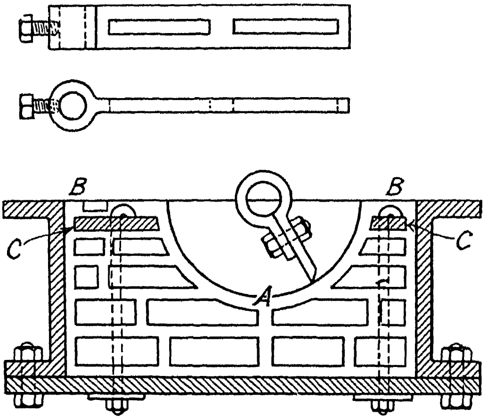


FIG. 45.—SPIDER ARM AT TOP, AND, AT BOTTOM, SECTION THROUGH HALF MOULD, SHOWING METHOD OF SWEEPING-UP LINER IN HORIZONTAL POSITION

Making a Medium-sized Sluice Valve Cover. Fig. 46 shows the pattern, which leaves its own core. Two joints are necessary, making a three-part job. A top part box, used here as a drag half, is placed, flange uppermost, on the floor, parting sand is sprinkled between the bars, and floor sand is rammed to about 1 in. from the top. Here an oval bed of dry-sand facing, a little larger in area than the bottom flange, is rammed on; outside this, floor sand, the surface being strickled off level with the edge. This is the bed for the pattern; also the bottom joint. The bottom core-iron, A, in Fig. 47, with an outside row of dabbers reaching half-way up the core, is put in the middle, the pattern is put on the bed—the top flange, B, having been previously removed, so as to leave, in the top of the pattern, a large opening, through which the core is rammed. In the middle of the core, a large vent plug, C, is placed, to pass through the drag part, and provide a means of escape for core gases,

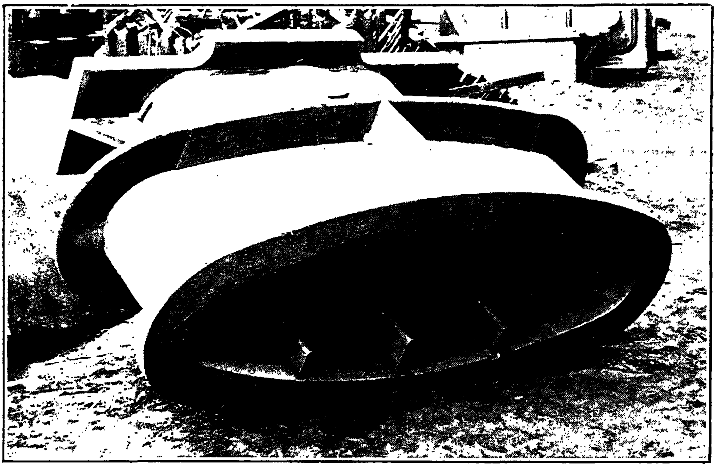


Fig. 46.—Pattern of Sluice Valve Cover constructed so as to leave its own Core

while two pegs are used to make holes to take the long bolts, D, holding the top iron E down to the drag part. The inside of the pattern is lined a little way up with facing sand, and about 6 in. of floor sand is rammed in the bottom. About 2 in. of facing sand is rammed round the inside of the pattern to a height of about 6 in., a number of small vents are made

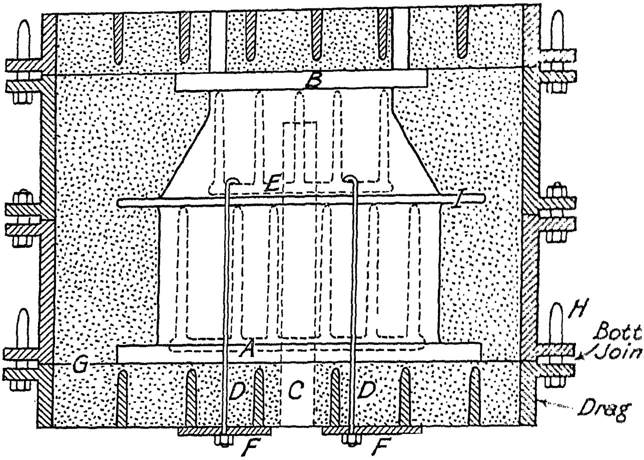


FIG. 47.—METHOD OF RAMMING-UP SLUICE VALVE COVER IN VERTICAL POSITION

in the sand close to the pattern, and the space, 6 in. deep, in the centre is filled with cinders or clinker. These 6-in. tiers, composed alternately of rammed sand, and of a shell of facing sand filled with clinkers, are continued to the top of the dabbers, venting round the pattern before each layer of cinders is rammed in. The cinders must make good contact with the centre vent peg. The pegs put in to form the bolt holes must be surrounded by sand over their full length, or cinders will fall in and choke the hole when the peg is removed. After each ramming of floor sand, a row of straight irons or lifters is laid horizontally round the inside of the pattern, about 1 in. back from the face. The core has now been rammed half-way up, to the top of the dabbers in core iron A. The two pegs D D are withdrawn, and the second core-iron, E, which must pass through the opening in the top of the pattern, is dropped in, and rests on top of the dabbers on core-iron A. Two long hook-bolts are passed down the holes D D and hook over the bars of core-iron E, which is firmly secured by means of the fishplates and nuts, F, underneath the drag. To do this, the drag, with the pattern and half-made core standing on it, must be lifted by the crane. Ramming of the top part of the core is now continued as for the lower, but, before the last layer of cinders—about 4 in. below the top of the core—is rammed in, the large vent peg, E, is withdrawn, and a piece of perforated sheet iron, expanded metal, or a few straight irons are laid across the top of the hole, to stop the cinders falling in, and to allow the gases to escape into it. The top 4 in. is now rammed with sand, 6-in. sprigs are knocked in all round the edge, the top face is vented into the cinders, and the flange B is bedded into position. A section through the core is seen in Fig. 48 (*a*). The loose sand round the pattern is cleaned off, the joint is sleeked with the trowel, and parting sand is sprinkled on, giving the lower joint, G. The bottom half of the middle-part box is located on the drag by the pins. This middle part carries, about 1 in. above the lower pattern flange, a row of bars, separately cast and bolted in (Fig. 48 (*b*)), to support the sand when the middle part is lifted later from the drag. Two runner gates are located at R R. A little facing sand is put on the flange and joint, and a few lifters, with their small ends hooking over the top of the bars, are laid on this, taking care to get a row of them on the flange near where it joins the body; also round the flange edge. These are required because, when the middle is lifted off, there is much friction at these places, as the sand slides up the pattern face. Facing sand is put round the base of the pattern, and lightly rammed between the lifters and bars; the pattern face is lined a little way up with facing, and floor sand rammed between the bars, continuing thus to the middle flange, I (Fig. 47), a row of straight irons being bedded in the sand all round the pattern after every second ramming, the last row being set just below the flange, I, which is now bedded in position. The screws holding the vertical ribs, bosses, etc., to the pattern must be removed as ramming proceeds. The upper middle-part box is put on, and bolted round the flange to the lower one. About ¾ in. of facing sand is laid on the intermediate flange, and clay-washed straight irons are put, $\frac{3}{4}$ in. apart, on this facing, and lightly bedded down. These irons prevent the sand above from falling away, on the removal of the flange in finishing. The ramming of the upper part is continued as for the lower, a few more straight irons being used to support

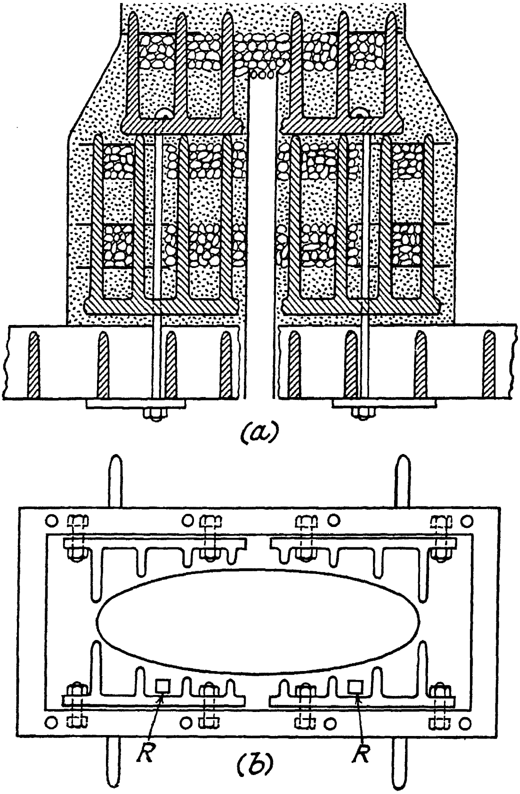


FIG. 48.—(*a*) DIAGRAMMATIC SECTION THROUGH CORE FOR SLUICE VALVE COVER; (*b*) PLAN OF LOWER MIDDLE-PART MOULDING BOX FOR SLUICE VALVE COVER

the sand at the ends of the pattern, where, owing to the acute taper, these parts of the mould are overhung. When the top row of irons, about 1 in. below the flange, have been bedded down, this part of the pattern is put into position, and the 1-in. space between the irons and the flange is rammed with facing sand, the outside edge being also covered, while floor sand is rammed to the joint. In describing the ramming-up of the outside of the pattern, no mention has yet been made of the runner gates, but these should be lined up with facing sand before every ram, and the sand between the down-gates and the pattern secured with rods, to prevent collapse into the mould in casting. No

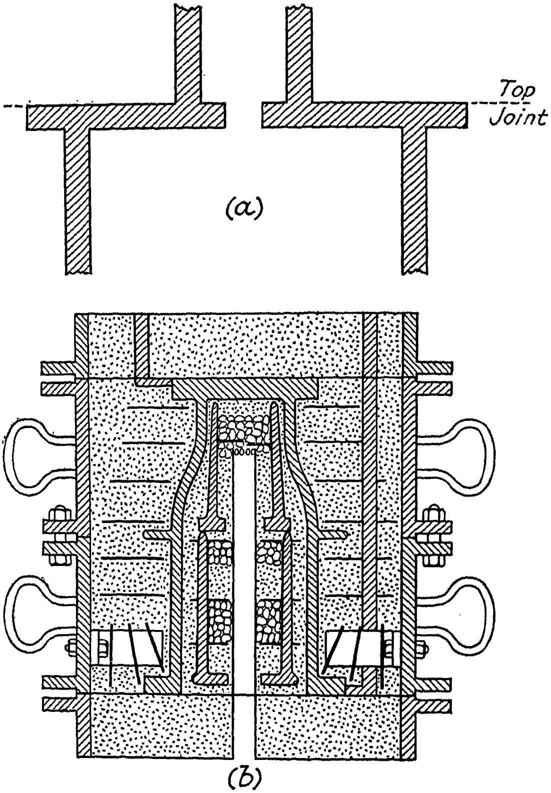


FIG. 49.—(a) DOWN-RUNNERS USED FOR CASTING SLUICE VALVE COVER; (b) SECTION THROUGH FULLY-RAMMED MOULD FOR SLUICE VALVE COVER

damage can be caused by the head pressure if the down-runners are encased by small cast iron bushes, as used for small work. The top joint, a plain flat parting, is made, and the cope registered on the middle part by another pair of box pins. The two down-gates are drawn out of the middle, the holes are covered with a thin piece of plate, and

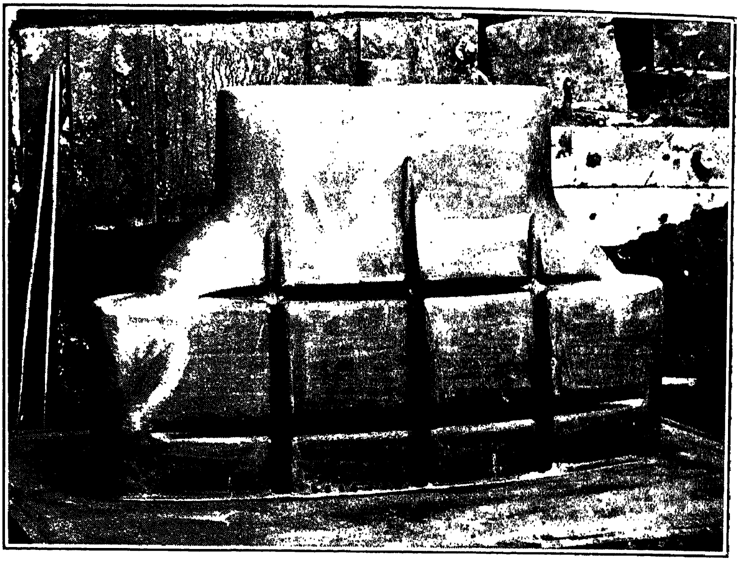


FIG. 50.—CORE FOR SLUICE VALVE COVER, AFTER DRYING

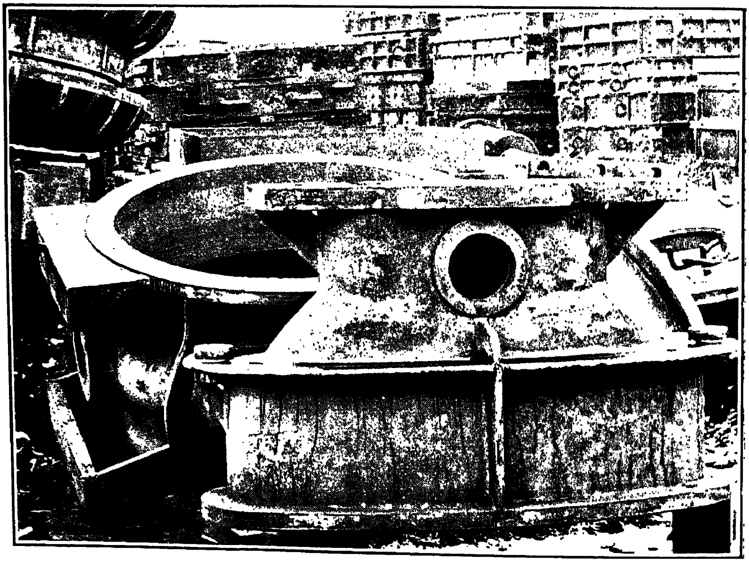


FIG. 51.—SLUICE VALVE COVER CASTING

the two runner gates are placed in between the bars of the cope, but now much nearer together than originally. Bringing the gates together allows a much shorter runner bush to be used when making the pouring basin, and serves also to break the fall of the metal into the mould. The final disposition of the down-runners is seen in Fig. 49 (*a*), the extensions on the horizontal portions trapping dirt entering with the first metal. Two riser pegs are inserted near to the flange, towards the ends of the pattern. Facing sand is sifted on to the pattern and joint, a few lifters are put in each bar, and the cope is rammed with floor sand. A section through the mould is seen in Fig. 49 (*b*), where the shaded pattern represents also the final casting. The ramming of the mould is now complete, and the cope is lifted off and turned over for finishing. Only a small flat portion in the middle will be in contact with metal in casting, and this part requires little finishing. The middle part is lifted off, and placed fairly high on stands, so that one can get into it. Since the loose pieces, centre flange, ribs and end bosses must be withdrawn, a fair amount of finishing will be required here. Because of lack of room, blacking is difficult. The pattern is drawn from the core, leaving the internal ribs, which have been dovetailed into the pattern. Soft places between the ribs, which are difficult to make sound on ramming, are now made good, are sprigged, and the ribs are removed. All the top surface is reinforced closely, using 2-in. sprigs, this part of the job being most likely to scab, if insufficiently dried or vented. After this part has been blacked, the whole mould is ready for drying. Fig. 50 is the dried core. The drag part is bedded on soft sand, a trench being led underneath, to bring off the vent from the core. The small round cores used to form the holes in the top flange and in the side, are fixed in their prints. After all sand, etc., has been blown off the mould and core, the three parts are closed together. After the box flanges have been bolted together, and the runner and riser bushes put on and made up, the job is ready for pouring. Fig. 51 shows the actual casting.

Making a Sluice Valve Cover from a Split Pattern. This casting can also be made from a pattern split on its centre line, as in Fig. 52 (*a*), the parts being dowelled together. The bottom half pattern—that having the print which takes the core to form the round hole at the side in Fig. 51—is laid, joint down, on a turn-over board, covered with dry-sand facing, and rammed up, with the following precautions. Two iron packing pieces, standing well above the flange, should be placed on the large core print at A A in Fig. 52 (*a*), and another on the small half print behind the rectangular flange at the other end. If desired, these three may be extended to touch the bars in the drag, for they support the two half cores in the mould, preventing their weight from crushing the sand round the prints. A small wooden peg should be rammed up on the round core print on the bottom side of the pattern under B. When withdrawn, this forms a hole in the sand, from the print right through the drag, through which to pass a long hook-bolt, attached to the core-iron in the top half core. This bolt, secured underneath the drag, prevents the small end of the core from lifting, which may not be avoided by relying only upon the

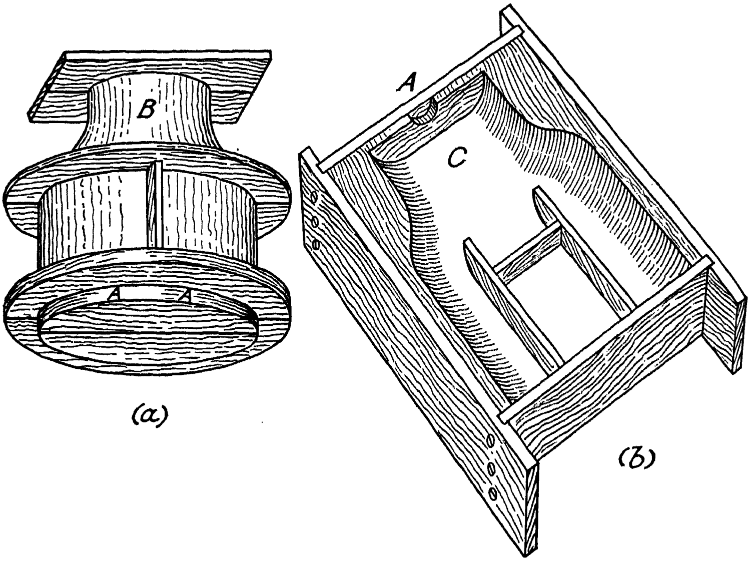


Fig. 52.—(*a*) Split Pattern for Sluice Valve Cover; (*b*) Half Core-Box for Sluice Valve Cover

small round print at the end of the rectangular flange. When ramming the cope, two packing pieces are also put on the prints over A A, and carried up to the cope bars, a similar piece being carried from the small print at the other end, these preventing the core from lifting. Only a half core-box need be used, as in Fig 52 (*b*). A single iron is used for each half, that for the bottom having strong dabbers immediately over the three packings on the prints, while the top half has strong dabbers directly under the packings in the cope. By casting, on the core-iron, an extension passing through a piece, shown dotted at A, cut out of the box, the bearing surface is increased. This extension can be supported on a distance piece between the packing in the mould and the core-iron. When making the bottom-half core, a plug is rammed up at C, to form a hole through which the hook-bolt from the top core passes, on closing. While the pattern constructed to leave its own core produces a casting of uniformly exact thickness and of excellent finish, the method is more costly than that of using a split pattern and core-box. The core is much less accessible than the two half cores made from the core-box and takes much longer to make. Two joints are required instead of one. When ramming the pattern on end, the much greater depth of moulding box causes a much larger number of changes in the sequence of moulding operations. There are at least three times the number of rammings, and the moulder has no sooner begun to use his rammer, than he must get down from the box to fill in more sand with his spade. He has, further, to line up the outside of the pattern with facing sand in 6-in. layers, this piece-meal lining being largely eliminated when the split pattern method is used. The vertical shell pattern is cheaper to make than the split pattern and core-box, requiring much less timber, a matter of much importance when only one casting is required, becoming a good deal less so, if a large number of castings are wanted. In this case, and if suitable jig-drilled boxes and a turn-over pattern plate are available, only a half-pattern need be made, when a large saving in timber can be effected. Again, such a design of half-pattern, with no projections to restrict the flow of sand, is admirably fitted for jar-ramming on a machine, when the time of ramming is reduced to a minimum. Also, when speed of production is important, dividing the work between the moulder and core-maker will expedite matters considerably. A wholesale use of cores cannot be recommended, however, and their avoidance will often reduce costs, both in pattern shop and foundry.

Strickle Boards for Sand Work. The use of strickle boards for sand castings should generally be restricted to small circular one-off jobs made in greensand, and larger one-off

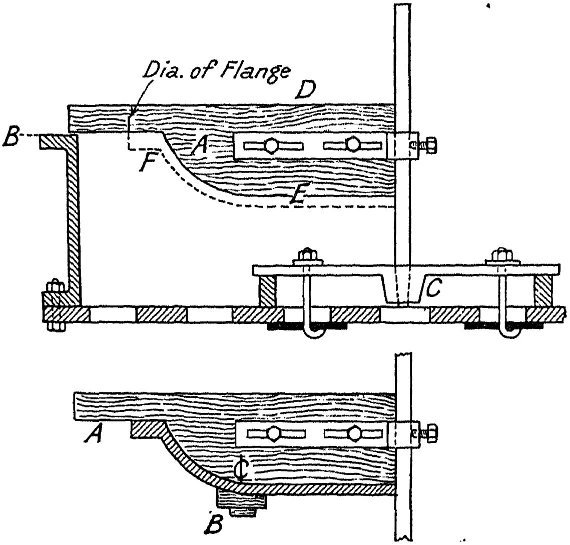
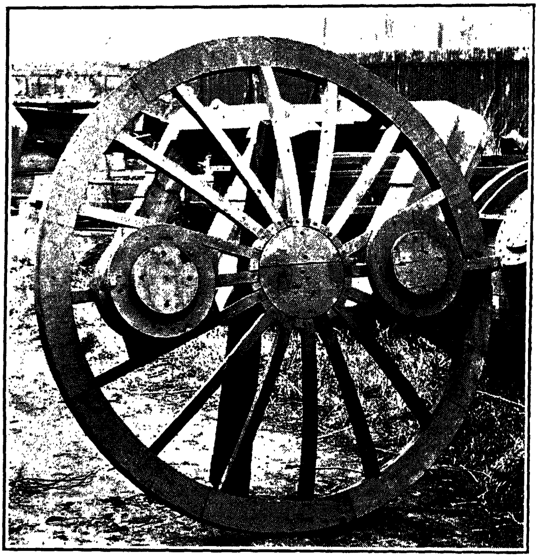


FIG. 53.—METHOD OF STRICKLING MOULD IN SAND FOR CONDENSER END COVER

jobs made in foundries lacking proper loam tackle. The moulding of a condenser end cover, strickled in sand, is described below. A spindle centre (*see* Loam Moulding) is bedded in the floor, well below the lowest part of the job ; or, alternatively, as in Fig. 53, is bolted in a box. If in the floor, the spindle must be vertical ; if in a box, the board A must revolve parallel with the edge. The centre bearing, C, should be well cleaned, and a little grease (not oil) put on the spindle. The board is attached by a spider arm, and the top edge, D, set at right angles to the spindle by a large set-square. The diameter of the flange is checked with a "size-stick," having a semi-circular hole to fit on to the spindle, and two arms of correct length in line. The moulding box is rammed with floor sand, the last 3 or 4 in. being sifted before ramming. By turning the board round, one forms a hollow depression corresponding with the interior shape of the casting. Before the board can be revolved, nearly all the surplus sand must be scraped away from in front of the board, so that only about ⅛ in. has to be removed by the board edge, E. To effect this, the strickle is worked round about 1 in. at a time, and pushed back again, the accumulated sand being removed from the front of the board. When the whole surface has been roughly strickled out, it will be found that the corner, F, is all broken away, and the surface is full of holes, due to the dragging along of pieces of scrap metal, etc., by the board. These defects are repaired by sifting floor sand on to the face, E, pressing it with the fingers into the surface, and scraping off again with the board. The edge, F, is repaired by throwing sifted sand hard on to the corner with a kind of spraying action, and strickling with the board after every throw. Sand must not be pressed on to the corner with the fingers, or it will break away again when the board passes. When the surface is good, the board and arm are removed, and parting sand is sprinkled over the surface. This forms the joint face on which the cope is rammed, as when using a pattern. Care is necessary not to ram the lifters below the face, nor to break away the sharp edge, F. If the spindle fouls a bar in the cope, it must be taken out before the cope is rammed, covering the hole with a piece of plate to stop sand falling into the centre bearing. The spindle should preferably be left in until ramming is complete, but must be removed before the cope is lifted off, and replaced directly afterwards. To form the drag-half mould, after lifting off the cope, the parting sand is brushed off the joint, and the bottom strickle board, shown in the lower half of Fig. 53, is bolted to the spindle, making sure that it is square, and that the edge A is clear—by about the thickness of a piece of paper—of the joint surface struck by the cope board. The diameter must be checked as before, or the metal thickness about the point

F may be wrong. Sand is cut away under the board, giving about 1 in. clearance all along the metal surface shown shaded on the board. This surface is left rough and vented well all over, passing the vent wire right through the bottom of the drag. The vent holes on the surface are repaired, and the loose bosses, B, are bedded in to their centre line, C, marked on the main strickle board, and set radially, with a straight-edge and set-square. Facing sand is now pressed on to the mould face with the fingers, and flat-rammed lightly, the surplus being scraped off, just as for the top board. The spindle, arm and No. 2 strickle board are removed, the spindle holes in the cope and drag are filled in, and the mould is finished, blacked and closed, as when working from a pattern. In using this type of strickle board, it is easy to obtain incorrect thickness on the bottom of the casting, by reason of the difficulty of setting the boards square, often because the spindle is not perfectly true. If the top-part board should be set high in the centre, and the bottom board slightly low at the spindle, the casting increases gradually in thickness towards the centre. If the error in setting is reversed, the casting will be thinner as the centre is approached. To correct these tendencies, the depth of the hollow in the drag should be measured near to the centre as soon as the cope is lifted off, a straight-edge being placed across the joint. After a few inches of facing sand have been strickled on to the drag by board No. 2, the depth is measured again, and should be as before, plus the metal thickness. This will generally be found incorrect, when one loosens the bolts holding the strickle board to the arm, and raises or lowers the board at the spindle end, as required. When making a large cover of this kind in the floor, a cinder bed, as described under *Venting*, must be made underneath.

Making an End Cover from a Skeleton Pattern. The same casting can alternatively be made from a skeleton pattern, as in Fig. 54. When three or four castings are required, they can be produced more economically in this way than by the previous method. To ensure that the flange shall be clean, this part is made at the bottom. A top-part box is used for the drag, this being laid on the



G. 54.—Skeleton Pattern for Condenser End Cover

floor and rammed with sand, a little facing sand being used to form the circle where the flange of the pattern will be seated. The surplus sand is strickled off level with the box-edge, and the pattern is laid on, as in Fig. 55. Two or three weights are placed on the outside edge of the pattern, to stop it lifting, and the centre is rammed with floor sand between the struts of the pattern to within 1 in. of the face. The portions in between the struts are well vented, pushing the wire right through the bottom of the box. The vents are closed near the pattern face, and facing sand is tucked under the pattern struts with the gagger-rammer, and rammed over the spaces between them, to just above their lower edge. The space between the bars of the skeleton pattern is now made good with floor sand, and shaped to the outside contour. When the periphery of the flange has been lined with facing sand, floor sand is rammed round, and the joint made, shown dotted. This completes the ramming of the drag, the remaining operations being as from a full pattern, except that, before the pattern can be taken out, most of the sand used to fill up the spaces between the pattern struts has to be cut away, while also, after the pattern has been withdrawn, the cod which is left on the drag has to be dressed to the required shape, because this part of the mould forms the inside of the casting. If the mould is in greensand, one must vent this part of the mould well, using a needle wire, to prevent it from scabbing. When several large covers of the same size are required, they can more economically be made in loam, for the shape permits this casting to be lifted from the mould without damage to the brickwork, when, for each succeeding casting, it is only necessary to face up the bricks with loam (*see* Loam Moulding).

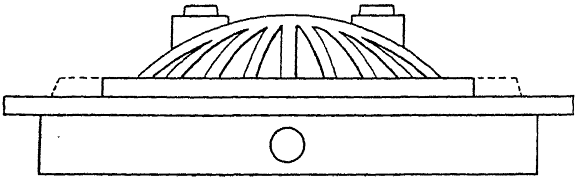
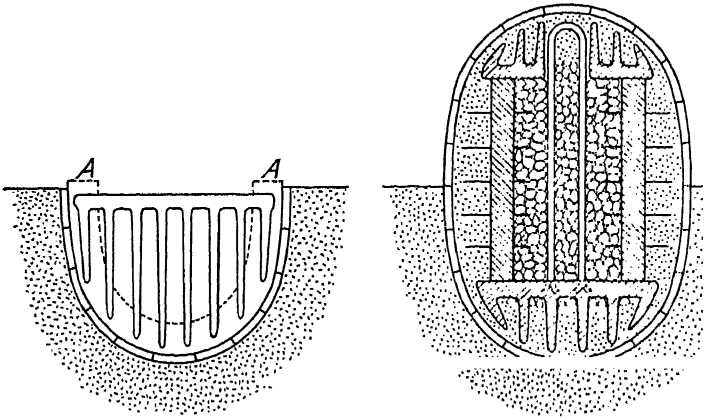


FIG. 55.—METHOD OF BEDDING-IN SKELETON PATTERN OF CONDENSER END COVER

If many smaller covers of similar design are required, it is best to use cast iron patterns leaving their own cores.

Thicknessing Moulds. Another method reducing the cost of pattern-making consists in the lining of the mould with slabs of stiff clay, "thickness clays," made the thickness of the casting. The lined mould is then used as a core-box. It is best to use split patterns. Centrifugal pump casings, adaptor pipes—which may be off-set and may change from square to round section—and similar castings, are readily made from a skeleton pattern, without core-box, in this manner. Fig. 56 (*a*) shows a half mould lined with clay, with the core-iron in position. When the skeleton pattern is withdrawn, the mould is finished, and the slabs—made in a special core-box from weak milled clay—are laid over the face of the mould. Interstices where the slabs do not fit close together are stopped with clay, and the core-iron is tried in, to see that the prodders do not project into the clay. About one inch of fairly stiff loam is now laid over the bottom of the clay lining, and the core-iron is clay-washed and set in position. A few lifters, reaching well up among the core-iron prodders, are stood on the loam, and about



(*a*) (*b*)

FIG. 56.—(*a*) SHOWING METHOD OF MAKING CORE IN MOULD LINED WITH CLAY; (*b*) SHOWING CORE MADE IN MOULD, PREPARATORY TO RAMMING OF COPE

3 in. of stiff loam is built up over the face of the core, to about the dotted line, the loam being also allowed to stand just proud of the joint line at A A. The thick layer of loam is partly dried by standing fires on the core-iron, the centre being now filled with cinders, which are covered on the joint with loam or sand. The joint of the core having been strickled off level with that of the mould, the core can be lifted out, and, if first bolted to a plate or top part, can readily be turned over for finishing. The core made in the bottom half mould remains bolted to its carrier until it has been dried, dressed and blacked, and again turned over, ready to lower into the mould. The cores are lifted out of the two half moulds, the clay thickness is stripped off the surface, and the mould is finished off and blacked ready for drying. Moulds must be either of dry-sand or loam, greensand being much too weak for this method.

A varying method of clay thicknessing, reducing still further the cost of pattern-making, and sometimes more economical in moulding, is also employed. Only a bottom half skeleton pattern is used. This is rammed in the drag, the joint is made and the pattern drawn out. The half mould is thicknessed with clay, but, instead of making only half a core, the complete core is made in the drag, the upper half being worked to shape by laying, on the mould joint, a suitable frame structure, with which a strickle can be used. When the core has been completed, the frame is removed, and the clay thickness is laid, this time on the top half of the core, thus making a kind of dummy pattern, on which the top half of the mould is rammed. Fig 56 (*b*) is a section through the mould and core, thicknessed ready for ramming up the cope. In this method, a strong bottom core-iron should be employed, while, if the core is a large one, a light top iron is advisable. This stands on packing pieces, built up from the bottom iron, and bolted to this in several places by means of hook-bolts. Fig 57 shows a mould for a large centrifugal pump casing being made in this manner. The half skeleton pattern has been removed, the mould has been lined with thickness clays, as shown, and the bottom half suction-core is being made, prior to ramming up the cope. When this half core is complete, thickness clays are laid over it, to complete the volute shape of the body core. The 2-in. diameter spindle is used to strike a seating for the cheek rings in the cores. Fig. 58 is a photograph of the casting.

Moulding in Cores. The building-up of moulds entirely or almost entirely from cores has long been practised, usually on medium-sized and large circular work, and, if only a few castings are required, the making of a segment core-box, from which a number of cores are made and finally assembled to make a complete mould, may save much of the expense involved in making a full pattern. Such a case is illustrated in Fig. 59, of a segment core for a flywheel casting. A number of these cores are set together in a circle, with a round core in the centre at C to form the bore, while a ring of slab cores is used to form the outside rim. With this type of mould, it is necessary to prepare, usually by the aid of a spindle and strickle board, a level bed, on which to assemble the cores, while the peripheral cores must be supported by ramming sand round the outside. This method can hardly be strictly described as moulding in cores, and one would not use it when larger quantities were required, for a method could always be devised more than compensating for the additional expense involved in pattern-making. In a somewhat different category is the production of small castings in core moulds, a practice which has been extended very considerably by the introduction of oil sand, chiefly because of the rapidity with which the cores can be made, and the great degree of accuracy in size and shape obtainable. This method is most suitable for small intricate work, such as is shown in Fig. 60, which represents a set of four castings, and the cores used to produce them, these cores having been made from a pair of half patterns. A common central down-runner is bedded in the back of one of the middle cores, and this connects with the in-gates attached to the half

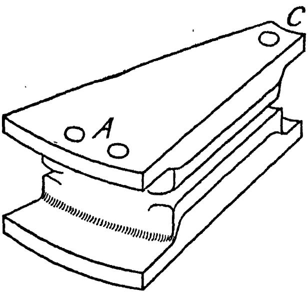


Fig. 59.—Segment Core for Flywheel Casting

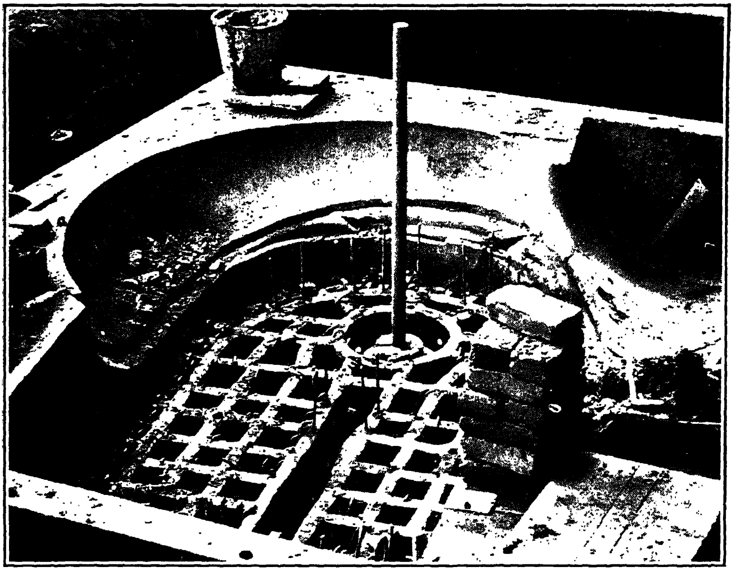


FIG. 57.—MOULD FOR LARGE PUMP CASING, SHOWING METHOD OF MAKING CORES

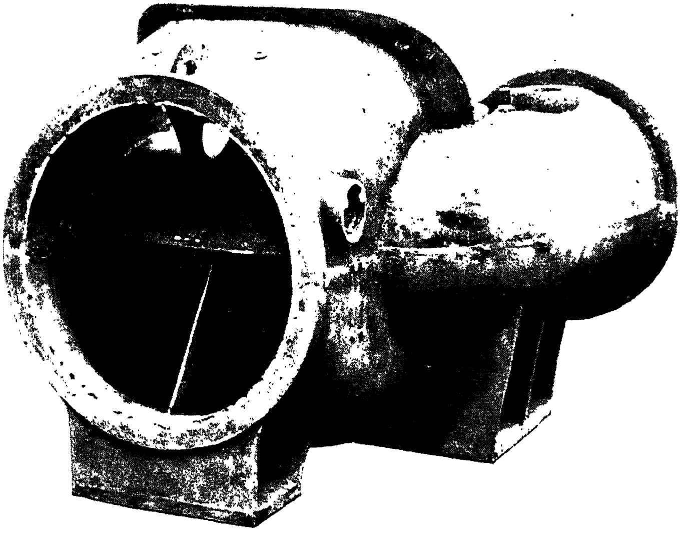


FIG. 58.—LARGE PUMP CASING, MODE OF CONSTRUCTION OF WHICH IS SHOWN IN THE LAST FIGURE. WEIGHT A LITTLE OVER 8 TONS.

Note fractures of tensile test-bars vertically under boss, and of transverse test-bar horizontally on joint beyond.

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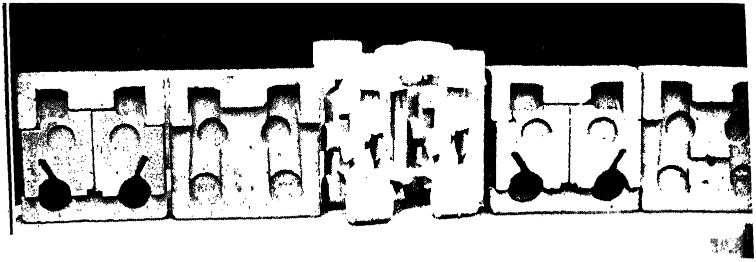

Fig. 60.—Group of Four Lever Castings, and the Cores required to produ
them

patterns. The riser gates are also attached to the pattern, and fairly large risers are required to feed the comparatively heavy bosses on these castings. The two half moulds are bolted together with plates, which are cast in an open-sand bed and are used also to carry the core-moulds when stoving. For work which is small but important, this method of manufacture has many advantages. The sand is harder and cleaner, the castings being particularly free from minor defects. Compared with the method of making from loose patterns, the quantity of sand used can be reduced considerably. There is less ramming and lighter handling, production being thus more economical. For small high-class castings made by the Lanz Perlit process, where the metal is poured into a hot mould, pre-heating, because of the lesser quantity of sand, is quicker. The simpler types of casting can also be made fairly cheaply in cores, the method most generally suitable being to cast in vertical stacks, using the back of the core as a covering for the mould contained in the core underneath, this arrangement being shown diagrammatically in Fig. 61. Such stack moulding of simple castings in oil sand of course cannot compete with modern machine moulding, but it is often much cheaper than loose pattern work.

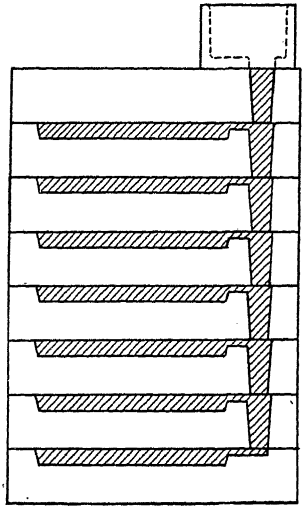
FIG. 61.—ARRANGEMENT FOR STACK MOULDING

CHAPTER V

PLATE AND MACHINE MOULDING

The experience necessary for the successful production of small castings from loose patterns is most required in making the joints, cutting the runners and risers, and in finishing the moulds after the patterns have been withdrawn. The removal of the pattern often damages the mould and necessitates "mending-up." Plate moulding was introduced to eliminate these three skilled operations as far as possible, and is therefore usually done by semi-skilled operatives. The process consists of mounting the pattern on a parallel-sided plate, usually of metal, of size extending beyond the edges of the boxes used with it, and drilled to the same jig. If, for example, the two halves of a split pattern are mounted, one on each side of a flat parallel steel plate, having pin holes drilled to the box jig,. by ramming a half mould from each side a complete mould is produced, as in hand-moulding. When the plate and pattern are lifted off the rammed half moulds, the box pins serve as guides and ensure an accurate draw. Further, the making of a joint, an operation always necessary with loose patterns, is eliminated. Patterns for plate moulding should be well finished, with the vertical faces free from undulations, so as to leave the mould without damage. Where possible, runner gates should be attached to the plate, this saving time in cutting them, and also serving to standardise the area of the gates for all castings made from the same plate. If part of a casting is to be made in the cope, and part in the drag, the pattern must be mounted on the plate so that the top part will register over the lower one on closing. For quantity production, as many patterns should be mounted on the plate as is safely possible. Patterns should be constructed to avoid the use of cores as far as possible. In mounting split patterns, the necessary halves are made from a master pair of half patterns, having double contraction allowance, the joints are surfaced, the halves are sweated together in pairs, the joints are trimmed, and two holes, countersunk on both sides, are drilled right through each pair. The halves are now parted, one set of halves being laid on one side of the flat plate and clamped in position, when the holes are continued through the plate. The corresponding halves are placed on the other side, and long brass rivets are passed through both halves, with the plate between, and riveted over in the countersunk holes. This leaves the patterns firmly fixed to the plate, as in Fig. 62 (*a*). The halves must be kept in pairs, as first fitted together, so that the joints will match when a half mould is rammed from each side, and closed for casting. When two or more castings are to be made in one box, the split patterns need not be mounted on each side of the plate, but can be accurately set out in relation to the pin-holes on one side only, as in Fig. 62 (*b*). If two half moulds, rammed from this plate, were closed together, two complete castings would result on pouring. It is unnecessary to have a flat parting plane when mounting on a plate; almost any shape of joint can be used. In Fig. 62 (*c*), a large part of the pattern is on one side of the plate, only the two lugs being on the other, the resulting casting being seen in Fig. 62 (*d*). When

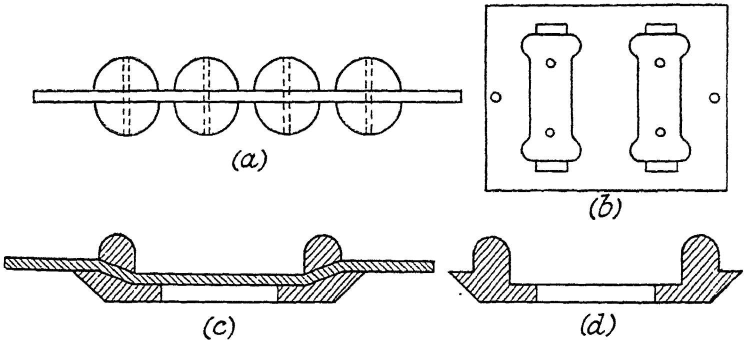

FIG. 62.—(*a*) METHOD OF FIXING PATTERNS ON A PLATE; (*b*) PAIR OF HALF PATTERNS MOUNTED ON ONE SIDE OF PATTERN PLATE; (*c*) SECTION THROUGH DOUBLE-SIDED MATCH PLATE; (*d*) SECTION THROUGH CASTING MADE FROM MATCH PLATE (*c*)

making double-sided plates with irregular joints, the plate is generally an integral part of the pattern. In the middle of Fig. 63 is seen a pattern plate of unit construction, for a manifold cover for a Diesel engine, the half moulds rammed from it being seen on each side. This type of plate is often called a match plate, for obvious reasons, and its use considerably simplifies production. The pattern plate is laid, dome downwards, on an empty box part, and the drag half put on it, locating the pins through the plate. This part is then rammed up, the crown of the dome only lightly. The box and plate are rolled over, the edges of the plate rapped and the pattern lifted off. The finished drag-half mould is seen on the right of the figure. To make the cope, the plate is again placed, dome upwards, on an empty drag part box, and the cope is put on and located with the pins in the drag part, these passing up through the plate and the lugs of the cope. A little facing sand is sifted over the pattern, and the box is rammed with floor sand. Because of the shape, there is no risk of scabbing in this part of the mould, which can therefore be rammed fairly hard. The rammed cope, the plate, and the empty part can now be rolled over, the pattern is rapped round the edges and drawn off, together with the empty box part, the pins in this part serving as pattern guides. The finished cope is seen at the left-hand side of the same figure.

Production of a Double-Sided Metal Pattern Plate. For any kind of cast metal pattern, a master wooden pattern plate must be provided. If the patterns to be attached to the metal plate and the final castings are of cast iron, the wooden patterns must have twice the normal contraction allowance, *i.e.*, $\frac{1}{5}$ in. per foot. For cast iron patterns and aluminium castings, the wooden patterns require to have the cast iron plus aluminium allowance. The construction of a double-sided plate, as that in Fig. 63, is illustrated in Fig. 64 (*a*), (*b*) and (*c*). The master pattern is rammed up in a box of larger area than the finished plate, a section through the rammed mould being seen in Fig. 64 (*a*), where A is the core print. The cope is lifted off and the pattern removed. A wooden frame pattern, $\frac{5}{16}$ in. thick, of the

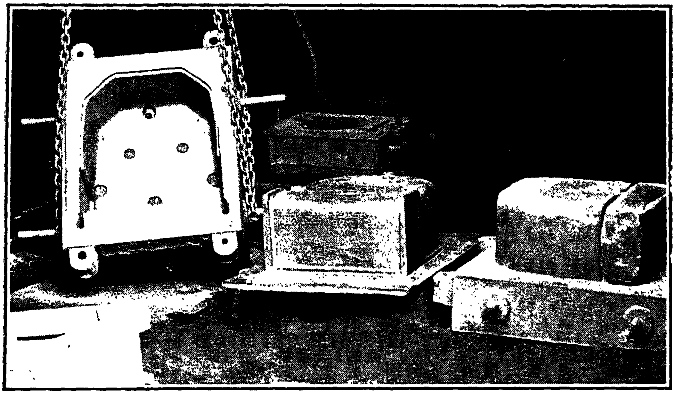

FIG. 63.—TWO HALF MOULDS AND PATTERN PLATE FOR COVER FOR DIESEL ENGINE MANIFOLD

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same width and length as the finished plate, is laid on the drag-half mould, as in Fig. 64 (*b*). Sand is rammed round the frame on the original joint, and strickled off flat, level with the top of the frame. This produces in the drag a flat plate mould round the impression left by the pattern, and raises the joint $\frac{5}{16}$ in. Spray runners are cut as at C, a flow-off riser is made at D, and the mould is finished as smoothly as possible. Fig. 64 (*c*) is a section through the mould closed for casting. The core used for the inside shape has been bolted down in the drag, and, as the joint is lifted the thickness of the plate, the box edges do not come together. Before clamping or bolting the cope to the drag, packing pieces must be inserted in the space between the boxes, so as to prevent the joint from crushing. The runner and riser bushes are put on, and the mould is ready for casting.

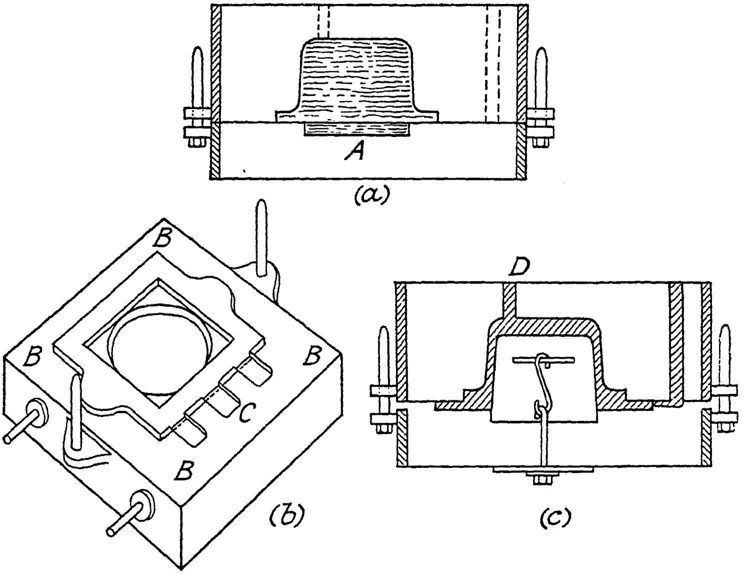
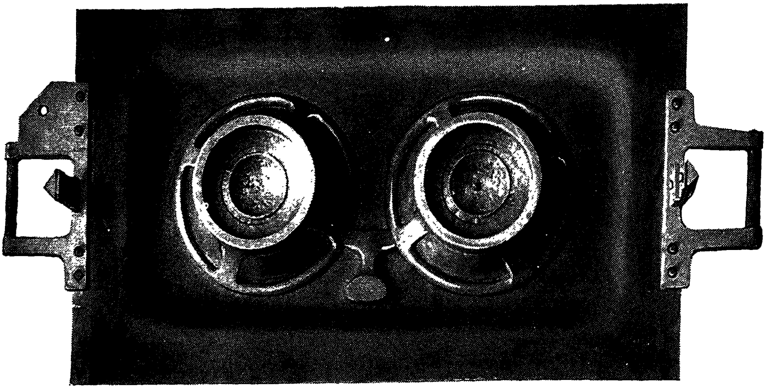


Fig. 64.—(*a*) Section through Pattern and Mould; (*b*) Frame Pattern for Plate, in Position; (*c*) Section through Plate Pattern Mould, closed ready for Casting

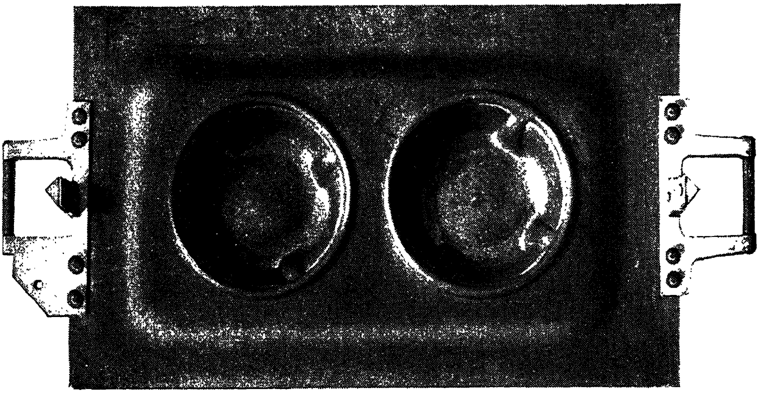
Cast iron, because of its low cost, is most used for double-sided metal plates, but it is much more difficult to get a smooth surface on an iron pattern than with the non-ferrous alloys. After the plates have been scraped and made fairly smooth with the file, a good surface can be obtained by warming and brushing a little beeswax all over, filling up any hollow places and removing the surplus wax with a suitable scraper. Plates thus treated must not be put near a fire, nor near moulds when casting, or the surface may be spoilt. Beeswax prevents the sand from sticking to the pattern. Defects can also be filled with plaster of Paris, but this may become loose if the patterns are rapped much. Cast iron plates should be stored in a dry place, to avoid rusting. Yellow brass or gun-metals make excellent plates, which are much easier to prepare, can be readily straightened if they warp on cooling, and will stand rougher handling than cast iron. They are little affected by the atmosphere, but are heavier and more costly. The weight of white metal makes it unsuitable for plate moulding, but it can readily be used for plates mounted on machines. Aluminium has several advantages. It is so light that large pattern plates can be lifted single-handed; it gives a good surface, is not brittle and can readily be cast into metal patterns. Figs. 65 and 66 show a pair of double-sided plates in aluminium, fitted with V-pins, for use with a snap-flask. Aluminium may corrode badly, giving a rough surface, if stored for long periods, but is not thus affected when kept in constant use.

Plaster and Metal Pattern Plates. A combination plaster and metal plate may usefully be employed when a comparatively small number of castings are required. One makes, from a master wooden pattern, two identical patterns, usually in cast iron, and rams a complete mould from one of these. The cope is lifted off, the spare metal pattern is placed in the impression formed in it by the first pattern, and one now has two half moulds, with a pattern lying in each. A cope part is put over the pattern in the drag half, and a drag part over the cope, filling up both with creamy plaster of Paris. When dry, the sand parts are destroyed, leaving the patterns fixed in the plaster parts. After retouching, the parts are ready for use. If the metal projects only a small way into the plaster, one or two short bolts screwed



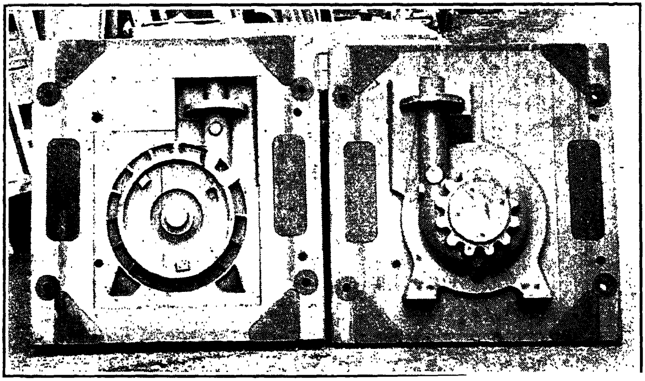
(*Macnab & Co.*)

Fig. 65.—Patterns Cast in Aluminium Match Plate (Top Side of Plate)



(*Macnab & Co.*)

Fig. 66.—The Same as Fig. 60 (Bottom Side of Plate)



in will prevent it from coming loose. Patterns thus mounted can be used for a large number of moulds.

Wooden Pattern Plates. Many types of casting can be made from wooden pattern plates, if a few precautions are observed. Wood is not so durable as cast iron, and the plates must be handled more carefully. Wood plates are unsuitable for large quantities of small castings, which must be made with very small tolerances in dimensions. No matter how well seasoned the timber may be, there is a tendency for these to shrink slightly when kept dry, while, if they are allowed to get damp, there will be serious trouble in another direction. For general engineering purposes, however, one can get excellent results from hardwood patterns mounted on hardwood plates. An advantage of this method is that, when split patterns or flat-backs are used, a number of different patterns can be mounted on the same plate, it being necessary, however, that they should be dowelled before being screwed fast, so that they can be returned to their respective positions when required. To avoid mistakes and also to facilitate locating, the patterns can be stamped with a letter beside their dowel pins, the same letter being stamped on the board at the side of the corresponding dowel holes. If one pair of dowels are larger than the other pair in the same pattern, it will prevent the pattern from being put on the wrong way round, the same purpose being served by using three pairs of dowels. When such a plate is available, it is often possible to mount on it patterns from which only four or five castings are required, so that they can then be more economically produced by semi-skilled labour. The employment of wooden plates sometimes involves a greater amount of core-making than when metal ones are used, but cores can often be avoided, an example being shown in Fig. 67, where the drag-half moulds are rammed from the plate on the left and the copes from that on the right. It will be noted that cast iron bushes are let in for pin-holes, while metal plates are used to prevent the moulding box edges from damaging the plate.

Stripping Plates. Stripping plates are used with patterns mounted on plates, where the shape renders it difficult for a perfect draw to be obtained by the ordinary method. They consist of flat parallel plates closely surrounding the patterns, and registered in position by the same means as the pattern plate. When the patterns are drawn, these pass through the stripping plate, which, being hard up against the joint, protects the mould from damage round the edges, where the draw is straight and comparatively deep. The patterns must be made deeper by the thickness of the stripping plate, or the depth of the castings would be reduced correspondingly.

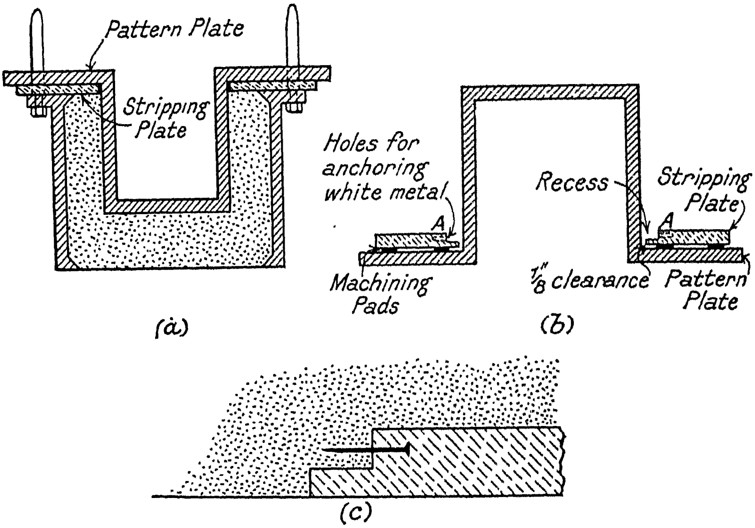


FIG. 68.—(*a*) SECTION THROUGH HALF MOULD, SHOWING STRIPPING PLATE; (*b*) METHOD OF WHITE-METALLING STRIPPING PLATE; (*c*) METHOD OF ANCHORING WHITE METAL

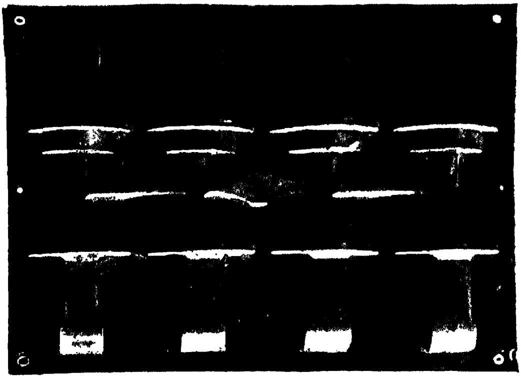
Fig. 68 (*a*) shows a section through a rammed mould, with stripping plate, turned over ready for drawing the pattern. The simplest form of stripping plate is made from mild steel plate, a thickness of about $\frac{3}{8}$ in. being suitable for small work. The opening for the pattern is marked off, and either milled out, or cut out with an oxy-acetylene flame, slightly smaller than the size required, being then carefully filed out so that the plate fits accurately but easily over the pattern. The plate is clamped to the pattern plate, and the necessary pin-holes are drilled through the jig plate, and reamered to size. When the outside shape of the pattern is such as to make the fitting of a steel plate very difficult, the problem can be dealt with successfully in the following manner. A cast iron plate is first made, having about $\frac{1}{8}$ in. clearance all round the metal pattern, and with a recess round the upper inside edge, as shown in Fig. 68 (*b*). The top side of the plate, *i.e.*, the recessed side, which forms the joint of the mould, is machined quite flat. The underside is provided with machining pads, which are machined parallel with the top face. Small holes are drilled in the plate all round the recess, and the plate is dropped into position, as shown in the figure. The $\frac{1}{8}$-in. clearance is packed with asbestos, a ridge of stiff loam is built up round the recess at A, the base of the pattern is given a thick coating of wet blacking, and the whole is put in the stove and made fairly hot. White metal is then run into the recess all round the pattern, the stripping plate being removed after the white metal has set, when the surplus metal standing above the plate is removed, the inside being trimmed round if necessary, so that an easy fit over the pattern is obtained. The purpose of the drilled holes in the recess is to anchor the white metal. There is a cheaper and more effective way of doing this, but it requires more care. In this method, a row of 1-in. wire nails are pushed into the sand which forms the recess in the mould, before the stripping plate is cast, so that the heads are finally left standing into the metal, as shown in Fig. 68 (*c*), when a secure anchorage is obtained. The method of finishing stripping plates by casting white metal round the patterns cannot be used when these are made either of wood or white metal, but it is quite satisfactory when the patterns and plate are of aluminium, brass or cast iron, and whether the pattern is cast integral with the plate, or cast separately, and fixed on afterwards. The only other matter concerning the production of plate moulds that need be mentioned is the moulding, where, after the sand has been mixed and sifted into a long heap, the operator begins to ram his moulds at one end of this. As the heap is gradually used up, so the pattern plate moves along close up to the end of the diminishing heap, the rammed moulds being placed on the floor behind. Thus the distance over which the sand and

the rammed moulds have to be carried is kept as short as possible.

Machine Moulding. Machine moulding constitutes an important section of the foundry industry, and one which, with the continual development of moulding machines, will become increasingly so in the future. If castings are required in sufficient quantity, and a suitable lay-out can be provided, machine moulding is nearly always cheaper than plate moulding. A possible exception is in the case of flat thin castings, such as are used for kitchen ranges, man-hole covers, frames, etc., where the boxes used must be very shallow in comparison with the area of the joint face, a circumstance which, in conjunction with the crossbars of the boxes, makes it very difficult to ram them satisfactorily on machines. But the same extreme shallowness of the boxes permits them to be rammed very quickly by hand.

The earliest types of moulding machine could only be used economically on certain special work. There are few jobs to-day on which production cannot be accelerated by the assistance of some type of machine. Since the installation of mechanical aids to moulding always involves additional capital expenditure, one must consider a number of matters before laying down the plant, particularly the type and number of castings to be made, and the suitability of any particular kind of machine for such production. If the machines are to be power-driven, a further capital charge will be required to lay down the additional plant, and there is, finally, the cost of maintenance. It is proposed to discuss here the uses of the various types of machine, and their relative advantages for different kinds of work. It should be unnecessary to give illustrations of the machines or to describe the mode of operation in full detail, for there is ample information of this kind in the catalogues of the makers.

Pattern Mounting for Machines. Practically all the methods of mounting patterns which have previously been outlined are suitable for machine moulding, although, in the case of many of the smaller machines, the plate has to



(*Macnab & Co.*)

FIG. 69.—SPLIT PATTERNS MOUNTED ON PLATE

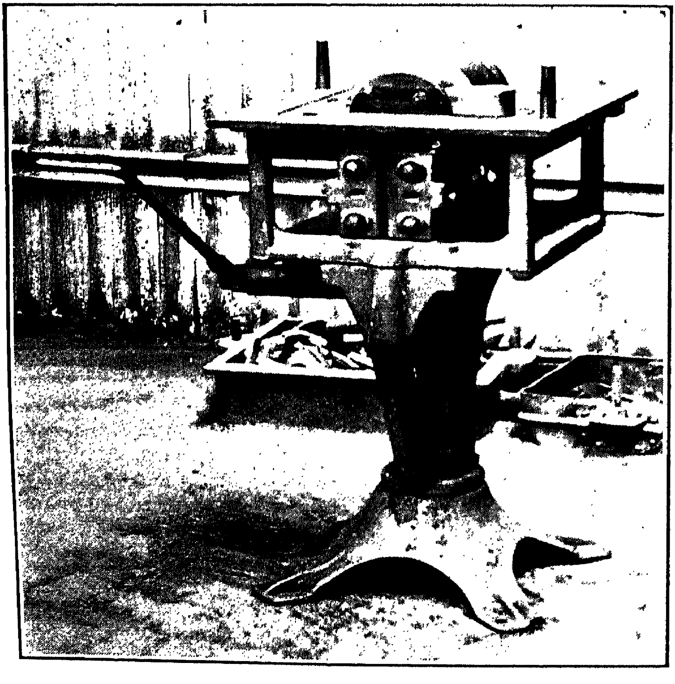


FIG. 70.—PRIDMORE PATTERN-DRAW MACHINE

be smaller than the moulding box, the locating pins being then mounted on the frame of the machine, the plate registering snugly inside the frame, with its upper surface level with that of the machine. Fig. 69 shows a pattern plate of this kind, located on the machine by two small dowel pins. When duplicate patterns are required to be mounted on plates, there are a number of proprietary liquid woods and cements which give excellent results. Although these preparations are somewhat expensive, their use in the duplication of small intricate patterns is often economical, while the patterns can be produced very quickly. When using cement, the method is as follows. The pattern is placed, with the flat joint face downwards, on a turn-over board, and covered with a moulding box, fine-grained red sand being sifted on to it, after which it is rammed up with floor sand in the ordinary manner. The half box is turned over, the pattern is taken out of the sand, and the mould is brushed over with a preparation of French chalk, specially provided for filling up the pores. The cement, which has been mixed with water to a fairly fluid paste, is now poured in, and, after standing for a little while, the surplus is strickled off level with the joint of the box. There is little or no shrinkage, and the pattern can be taken out of the sand next morning, cleaned off, fixed permanently to its plate and given a coat of varnish, being then ready for use.

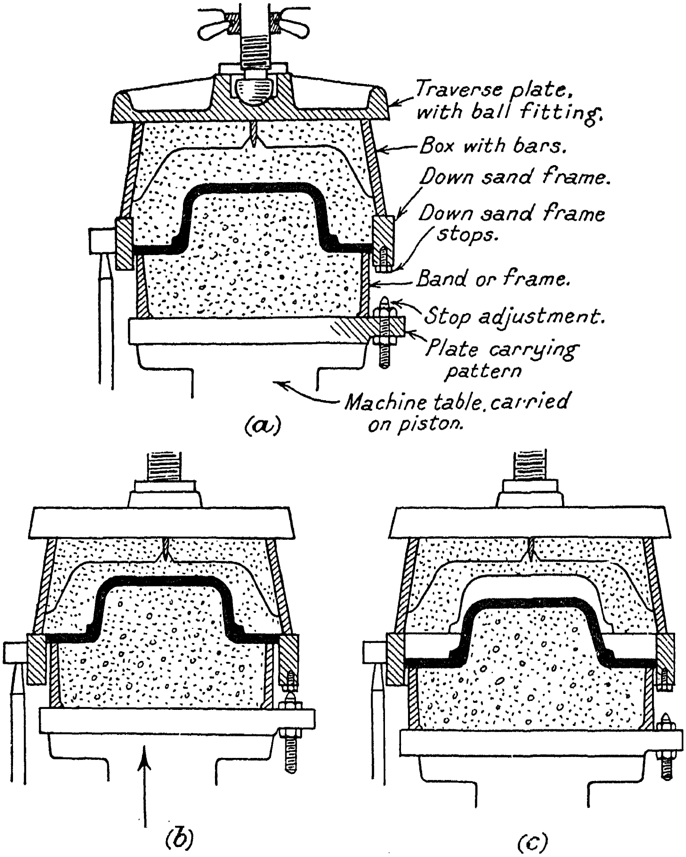
Pattern-Draw Machines. The simplest type of moulding machine is hand-operated, and serves only for the purpose of withdrawing the pattern, an example being shown in Fig. 70. The pattern plate is located by means of two small pins on the inside frame, which is so set that the surface of the plate is level with the outside stationary frame. The moulding box parts carrying the pins are positioned by means of two holes drilled in the machine frame, the cope being located on the pins fixed in the machine. When the half mould has been rammed up, as in plate moulding, the pattern with its plate is drawn downwards out of the sand by pulling the handle slowly over, a straight draw being ensured by V-shaped guides, which are adjustable for wear. If the pattern has been properly finished, and tapers slightly, quite difficult draws can be obtained without damage to the mould. When necessary, rapping the plate on the underside can also be resorted to. If the sides of the pattern are deep and parallel, it may be necessary to use stripping plates, for which this machine is very suitable. To avoid too frequent changing of the plates, all the drag-half moulds are put down first, the cores, if any, being placed in position before changing the plate for ramming up the top parts, when, as these are rammed, they are at once placed on the drags.

For larger work, one uses pattern-draw machines operated by hydraulic power, these consisting of a cast iron frame table, which can be revolved by hand through gearing. The pattern plate is bolted to the table, and, after ramming up the half mould, the box part is also bolted to the table. The pattern plate and mould are then raised by means of two hydraulic cylinders, one on each side of the machine, and turned over. A small bogie is run under the machine, the box being lowered on to it. The bolts holding the box to the machine are taken out, and the pattern is drawn upwards out of the mould. The use of hydraulic power gives a very steady and dependable draw, but care must be taken to have the box properly seated on the bogie before the bolts are removed, or it may tilt slightly, so as to spoil the draw.

Compressed Air Squeezer Machines. There are in use a considerable number of machines designed to press the sand into the box, thus rendering hand-ramming unnecessary. Those worked by compressed air are used chiefly on smaller work, and generally press the sand into the moulding box downwards, the pattern being also mechanically drawn. These machines are particularly suitable for work which is shallow or comparatively so, and they are very fast in operation, the total time for squeezing and drawing the pattern being only a few seconds. The pattern can often be so mounted that both drag and cope can be rammed from the same plate. When only one pattern is mounted on the plate, unless both half moulds are alike, the plate must be changed for ramming up the cope. An alternative method is to use two machines, one for ramming the cope and the other for the drag. Some squeezer machines are hand-operated, these being capable of dealing with a wide range of work of a comparatively shallow depth, but they cannot compare with power-operated machines in speed of production.

Squeezer machines are less successful on deep work, where the friction set up by the sides of the moulding box and the vertical sides of the pattern resists the flow of the sand when the pressure is applied, so that the sides of the mould may be soft. If, in an effort to overcome this defect, the pressure is increased, the bottom of the mould will be too hard. This ineffective ramming makes the castings rather rough on their vertical faces, an effect particularly noticeable when casting gun-metal or phosphor-bronze—where the penetrative tendency of the molten metal is much greater than with cast iron. The difficulty can be partly overcome by leaving a hollow place in the sand-measuring frame over the pattern, before applying the pressure, when more sand is pushed down the sides of the pattern, and less on top of it. If necessary, the mould can be hand-rammed a little between the box sides and the pattern, before finally filling up for squeezing.

Hydraulic Squeezer Machines. Hydraulic power is also extensively used for squeezer and other machines. The hydraulic squeezer gives what is undoubtedly one of the quickest methods of producing shallow work, but this machine is not suitable for deep castings. The ramming of moulds by squeezing the sand down into the box is most successful for work which can be made in boxes whose surface area is so small that there is no need of any crossbars to hold the sand in the box. Hydraulic power is used for ramming quite large moulds, but, instead of the sand being pushed down on to the pattern, the pattern is pushed up into the moulding box, so that the sand is rammed hardest near to the mould face—entirely the opposite effect to that obtained when the pressure is applied to the backing sand. The type of squeezing now being described has come to be known as the " down sand frame " method. The pattern plate when on the machine is sunk below the joint face inside a frame which is slightly smaller than the moulding box. When the box is filled with sand, hydraulic pressure is applied underneath the plate, so as to push it up until it is level with the edge of the moulding box. The method is illustrated diagrammatically in Fig. 71, which



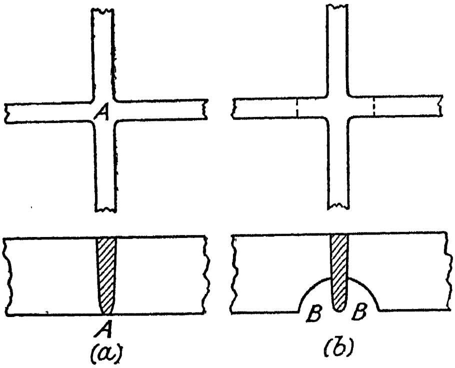
(*Universal.*)

FIG. 71.—METHOD OF WORKING DOWN SAND FRAME; (*a*) BEFORE RAMMING (*b*) AFTER RAMMING, (*c*) DRAWING THE PATTERN

shows the pattern plate in the three positions. While the "down sand frame" method of squeezing moulds is used chiefly for medium-sized and fairly large castings, there is another branch of founding in which the use of machines working on this principle is the only method that can economically compete with plate moulding. This is the production of stove and grate castings, where the boxes used are of comparatively large area, but very shallow, and where no other machine-moulding method is able to ram the sand satisfactorily under the crossbars of the boxes.

Magnetic Squeezer Machines. A new type of magnetic squeezer machine has been devised and patented by British Insulated Cables, Ltd., and is marketed in this country by Pneulec, Ltd. The outstanding advantage of this machine is that it is a complete and self-contained unit, requiring neither hydraulic nor pneumatic plant. The power costs are very low, the makers' figures for the smaller machines, when ramming 30 moulds per hour, and with the cost of electricity 1d. per unit, being a fraction over 1½d. per 8-hour day. Quite apart from the economical advantages of such machines to the well-equipped foundry, there are many small foundries whose production does not warrant the installation either of hydraulic or pneumatic plant, and to whom, therefore, if their class of work is within the limits of such a machine, it should prove extremely useful.

Jolt- or Jar-Ramming. Extensive use is made of machines working on this principle, which, in the case of heavy work, enables the ramming of the moulds to be performed in the most expeditious manner. The method is also applied to comparatively small work, where, however, it is usually a little slower than squeezing. After the moulding box has been placed in position, the pattern on the plate is covered with facing sand, filling up with loose sand, and using also a wooden frame, 3 or 4 in. thick, to hold an additional quantity of loose sand above the top of the moulding box. The whole is lifted a few inches by air pressure and allowed to drop back by gravity to its original position, the operation being many times repeated. When the table of the machine comes to rest at the bottom of the stroke, the sand tends to pack down against the pattern plate. The number of jolts necessary to ram the moulds to the correct hardness is found by experience, depending upon the severity of the jolts and the size and shape of the pattern. Jolt-ramming packs the sand hardest on the pattern face, the density becoming progressively less towards the top, the upper surface being often quite soft, so that, after jolting, the boxes are flat-rammed before being taken off the machine. Any overhanging portions of the pattern restrict the flow of the sand, the mould under such parts being nearly always too soft. Small loose pieces, if they do not project very far, can sometimes be dovetailed on to the pattern, so that, after the pattern has been withdrawn from the mould, the soft place immediately under the projection can be made good before taking it out of the sand. When the overhanging portions are large, however, the patterns are unsuitable for jolt-ramming, and such parts must be blocked out to the mould joint and afterwards covered with a core. This interference with the sand flow is also found directly under the box bars, and, when these come near to the pattern, the mould may be very soft at this point. The difficulty is partly overcome by streamlining the bars on the underside. When cope bars run in two directions, there is, with the usual design, a comparatively large area under the junction of the bars where such an effect may be produced, this being illustrated at A in Fig. 72 (*a*). By cutting away the short bars that connect to the main cross bars, as at B B in Fig. 72 (*b*), the occurrence of a soft place can to a large extent be avoided.



(*a*) (*b*)

Fig. 72.—(*a*) Unsuitable and (*b*) Correct Arrangement of Box Bars for Jolt-Ramming

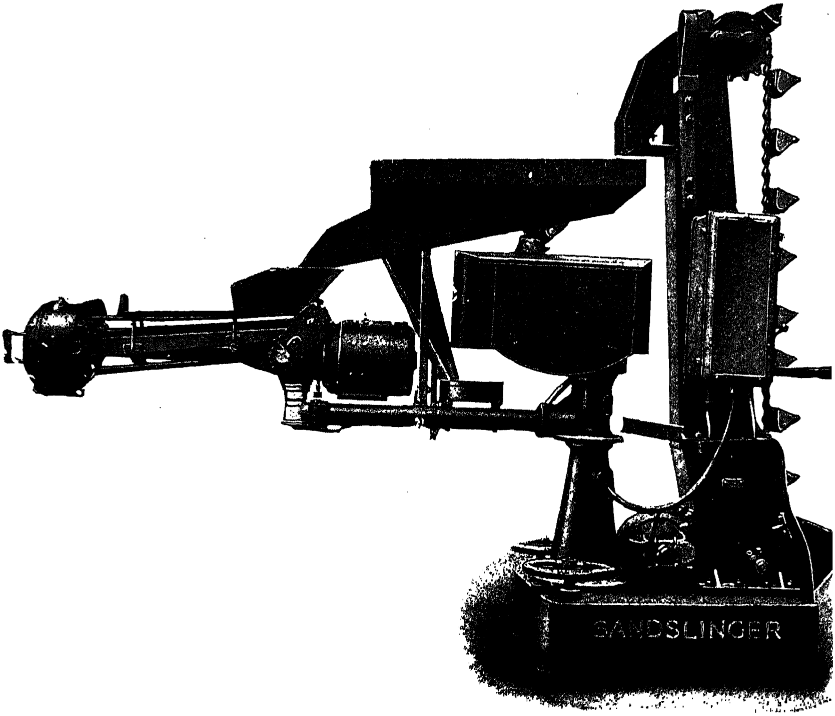
Jolt-Squeeze Machines. Before discussing jolt-ramming machines in greater detail, it should be useful to consider briefly the process of ramming by a combination of jolting and squeezing, particularly because it is commonly applied to the production of smaller castings than in the case of plain jolting. Jolt-squeeze machines are excellent for making small and comparatively deep castings, which cannot be rammed satisfactorily by pressure from the top. Although most of this work could be rammed by plain jolting, this would take longer, chiefly because of the time taken to flat-ram the sand on top of the box and to strickle off the surplus. By first giving a few jolts to pack the sand close to the pattern, and particularly down the sides, afterwards finishing off the ramming by squeezing from the top, a well-rammed mould is obtained, the time taken for the complete operation being only a few seconds longer than is required even to squeeze a mould which is plain and shallow.

Plain Jolt-Ram Machines. Such machines are commonly used on general work when the quantities required are insufficient to warrant the installation of a special-purpose machine. The sizes most generally employed have lifting capacities from about 1 ton upwards. Besides being very suitable for ramming half moulds mounted on plates, they are frequently used for ramming-up the drag half of a mould containing a loose pattern, the cope being afterwards rammed on the pattern by hand in the usual way. When using a machine of this type, the plate on which the pattern is mounted must be bolted or clamped to the moulding box, so that these can be lifted off the machine and turned over together, before drawing the pattern. When dealing with loose patterns, the usual practice is to lay them on a suitable board or plate which can readily be fastened to the box; otherwise the sand and pattern would be likely to fall out when the box is lifted off the machine after jolting. The filling of large boxes by hand for jolt-ramming is a very fatiguing business, and, unless some special mechanical provision is made for this, the machine should be set in a pit in the foundry floor, so that the table is only a few inches above the ground level, a suitable wooden stage being fitted round the machine over the pit, to prevent this from becoming filled with sand. Modern machines for plain jolt-ramming are so designed that the shock is taken uniformly over the whole table and there is little or no tendency for the box to move about when the machine is in operation. It is therefore seldom necessary for the box to be clamped to the machine table.

Jolt-Ram Pattern-Draw Machines. When large numbers of similar castings have to be jolt-rammed, production is facilitated if, in addition to ramming the sand, the pattern is also mechanically withdrawn, while the mould is still on the machine. A number of machines of this type are in use, operating generally by means of compressed air which is separately generated.

Jolt-Ram Turn-Over Pattern-Draw Machines. As the name implies, these machines ram the mould, turn it over, and draw the pattern upwards out of the mould. For medium and fairly large work, they have several advantages over the types previously described. Since the pattern is drawn in an upward direction, stripping plates, even for the deepest of lifts, are unnecessary. The half moulds can be turned over much more readily by the machine than by one of the foundry cranes, and, if a crane has merely to lift a mould off the machine, it can be more quickly released for other important work. Many similar machines by various makers are on the market, being designed in some cases for turning over very heavy loads. These larger machines are set a considerable distance in the ground, and require a heavy concrete foundation and a large bricked pit, which is boarded over, so that the various working parts may be accessible for cleaning, oiling and the making of the necessary repairs. Before coming to any decision as to installing a particular machine, it is advisable to see one or two of the machines which are operating on work similar to that required to be done by the prospective purchaser.

Sand Slinger Machines. These general purpose machines embody a principle of ramming which is followed by every skilled moulder when dealing with certain inaccessible parts



(*Foundry Plant & Machinery, Ltd.*).

FIG. 73.—PORTABLE TYPE SAND SLINGER

of the mould, particularly in greensand work. In such cases, the moulder throws sand, a handful at a time, hard into the part in question, the velocity of the flying sand ensuring a tight and even packing, which cannot be obtained by hand-ramming. The mechanical sand slinger was developed in the United States, but at the present time many of the medium-sized and large general foundries in Europe are equipped with one or more of these machines, which have often been specially adapted for small repetition moulds, but are generally used for ramming medium- and reasonably large-sized dry-sand moulds. No special tackle in the way of moulding boxes, or pattern mounting, is necessary. Standard loose patterns are quite suitable, but it is better to have the drag-half boxes without crossbars, covering them with loose grids, as with the built-up box shown in Fig. 32. When using split patterns where one half is rammed in the cope, the same remarks may apply to these halves, but these arrangements in no sense constitute special tackle, representing, indeed, standard practice in many foundries. Sand slingers are of several different types, known as stationary, portable, tractor and locomotive machines, but they all operate on the same principle. Fig. 73 shows one of portable type. If the delivery head is kept moving steadily about, the sand is continuously packed quite hard, but, if the head is allowed to remain too long in one position, the sand piles up in a heap, some of it tending to roll down the sides, the mass being softer in places. The method of ramming with this machine should be briefly described, as follows. If no suitable board is at hand, an empty box part is turned over and put on the ground, rammed full with sand by the slinger, strickled off level, and used as an odd-side on which the pattern is placed for ramming the drag. The pattern is now covered with facing sand, which should be pressed firmly to it, any pockets or delicate corners being reinforced by pushing in a few sprigs or irons, and ramming lightly with a hand-rammer. The middle-part boxes are now put round the pattern, leaving off the grid, so that there is nothing to break the fall of the sand. The machine is again set in motion and the box is rammed full, care being necessary so to direct the head of the machine that the sand being slung down does not knock away the facing sand from the upright walls of the pattern. The surplus sand is now strickled off, the covering grid is put on and bolted to the box flanges, sand is slung in between the grid bars, and the whole is rolled over for making the joint. When dealing with the cope, if the pattern stands above the joint, ramming is facilitated if grids of core-iron type are put round the pattern; indeed, for sand slinging, grids should always be used, if possible, rather than the method of liftering through cope bars. By using grids, it is often possible, after they have been put on, to cover the pattern completely with facing, and then to sling right up to the top of the box, using a loose covering grid, as for the drag half. If the joint and top face of the pattern are rather flat, and therefore unsuitable for lifting with grids, the top part must be placed in position, and lifters put in, as necessary, in the ordinary manner. Sand must then be tucked under the box bars and into any pockets by means of a hand-rammer, ramming being completed with the slinger. It is not always necessary to move the machine to the moulding box, it being often quicker to move the box to the machine. It is always necessary, however, to have adequate lifting facilities, and also a sufficient supply of mixed sand ready behind the machine. Here the Royer Sand Mixer, shown in Fig. 3, may often be used with advantage.

The locomotive-type slinger is provided with a bunker capable of holding about 10 tons of mixed sand. One of the best arrangements for this machine is to have the track in the middle of a fairly wide bay, from 40 to 60 feet across, with a sand-conditioning plant at one end. The skilled moulders prepare the patterns, as just described, along each side of the track, preparatory to slinging, and the machine, having filled its bunker at the conditioning plant, moves under its own power along the two rows of moulding boxes, as they become ready. It may be necessary for a moulder to have two, or even three jobs at a time, so that he may not have to wait while one box is being rammed, or while the slinger is engaged elsewhere. The tractor type of machine is designed to travel slowly on a special wide track along the foundry floor, picking up sand from a heap between the rails, while, as the moulds are rammed, they are left behind in the track for finishing and casting. This type of slinger is often used, in conjunction with pattern-draw machines, such as the Pridmore shown in Fig. 70, for ramming-up repetition moulds which are quite small. The pattern-drawing machines are then fixed to a special frame which is attached to the slinger and is pulled along by it, the delivery head being swung in turn over each machine, for ramming a half mould. The drag-half moulds are then placed on the floor in the casting position and the cope halves are closed on them almost at once from another machine. There is little doubt that, in order to be successful, sand slingers require a special foundry organisation, depending upon the type of machine being used, and which may be somewhat as indicated.

Moulding Machine Lay-Out. It is intended to deal with this subject mainly as it affects the production of small moulds, and only in a lesser degree with medium-sized and large moulds made on jolt-ramming machines. The methods and lay-out necessary for ramming by sand slingers have just been discussed. When one considers that the squeezing of a half mould takes only a few seconds, and that most of the largest moulds can be jolted in less than one minute, it will be obvious that the various other operations that are necessary for the making of a complete casting offer a very wide scope for efficient organisation. In the first place, all moulding boxes should be ribbed, so that they will not be distorted by the pressures induced either by squeezing or jolt-ramming, and should be ground flat on the joint face. One can frequently use, for machine moulding, boxes which have not been machined, especially if chipping pieces have been cast on the corners, but the results are not always satisfactory, and the small extra expense of machining the joints will be fully repaid. The problem of supplying an adequate amount of mixed sand cannot be lightly dismissed. The quantity of sand required for a given weight of castings varies considerably with the class of work, about 1 ton of sand for 2½ cwt. of castings being an average for small work. This sand must be turned over at least twice when mixing, and must still be lifted into the box, so that at least 3 tons of sand must be handled to ram enough moulds for 2½ cwt. of small castings. Not only lifting, but also transport of sand is involved, because, when the boxes are filled by hand, no matter how near to the machine the mixed heap may be when the operator begins to ram his boxes, the more sand he uses, the further has he to carry the remainder. The same applies in the filling-up of boxes for jolt-ramming, except that, as the boxes become larger, the amount of sand for a given weight of castings generally gets smaller. But the filling-up of a large box with sand by hand is a fatiguing job, in no wise conducive to rapid production, and this can be much accelerated by having the prepared sand stored in a hopper over the machine, and run out as required. The hoppers can be made of mild steel plate, or of wood, the former being cheaper. For hand-ramming, where the sand is added in small quantities, the hopper is fitted with a simple chute that can be opened or closed by the operator at will. For small power-squeezer machines, the sand is added all at once in amount sufficient to ram one half mould completely, and a special device, as in Fig. 74, is advisable. This is attached to the mouth of the hopper, and holds the required quantity. When pulled down at the front to allow the sand to flow into the box on the machine, the circular back of the attachment shuts off the main hopper along the dotted line,

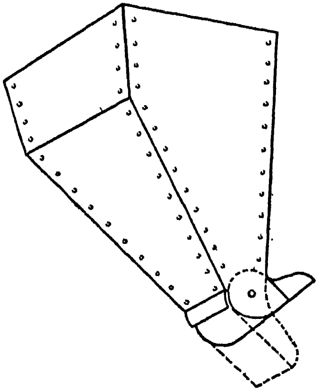


Fig. 74.—Sand Hopper with Measuring Device

so that only the required quantity falls. For larger machines, one has a delivery chute which can be kept open until enough sand has fallen into the box, being then closed by hand.

Sand Preparation. Many varieties of sand-preparing plant are used, and, since there are a number of firms specialising in this plant, it is proposed only to describe briefly one or two methods of avoiding much of the labour of sifting, mixing and delivering to the machines by hand. On the market there are portable machines, which will sift the sand and throw it some 9 or 10 feet through the air, being thus sometimes used for loading small hoppers. The disadvantages are that the sand must be mixed by hand near to the hoppers, the loading device must be moved about from place to place, and the wear on some parts of the machines is heavy. If only two machines are used, they can be fed quite simply, as in Fig. 75. The sand from the previous cast is knocked out near the elevator, the required amount of water is added, and the sand is mixed by hand, being passed through the screen to fall into the boot of the elevator, by which it is discharged into the common hopper, A, with separate chutes, B B, for the two machines. This apparatus is conveniently driven by an electric motor, working through reduction gearing. If the sand is used in jar-ramming large moulds,

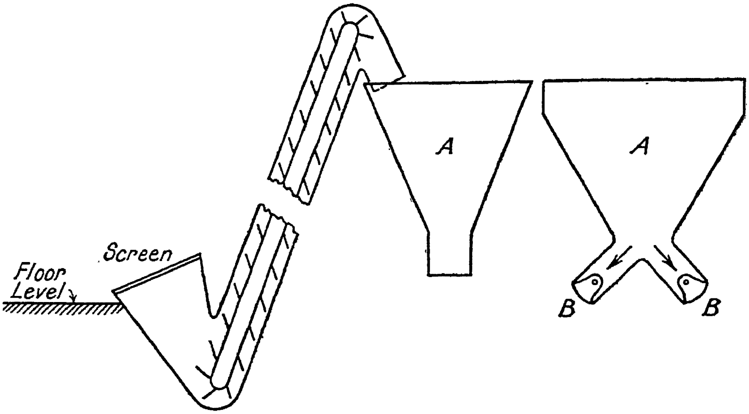


FIG. 75.—SIMPLE SAND-MIXING PLANT FOR FEEDING TWO MACHINES

the mesh of the screen can be fairly coarse, but, for small work, a reasonably fine mesh will be preferred, in which case the screen must oscillate or vibrate, so as to pass the sand freely through it. By inclining the screen as shown, the reject will be caused to fall out at the front. For the supply of much sand to numerous hoppers, a more elaborate lay-out, as in Fig. 76, will be required. Used sand is knocked out at the foot of the elevator, and, after moistening, is pushed through the grid into the elevator boot, being raised to the vibrating screen and falling on to the belt conveyor, from which it is removed by adjustable scrapers to fall into the machine hoppers. If desired, a magnetic drum can be arranged to rotate off the end of the screen, to separate metal scrap. Fig. 77 gives a suggested lay-out for a machine foundry making only small repetition work. The metal is tapped into two ladles mounted on trucks, which run the length of the floor, hand-shanks being used for casting. Opposite each machine is a roller conveyor—inclined slightly downwards in the direction of the arrows—on which the moulds are placed as soon as they are made. After casting, the boxes are knocked out over the gratings at the cupola

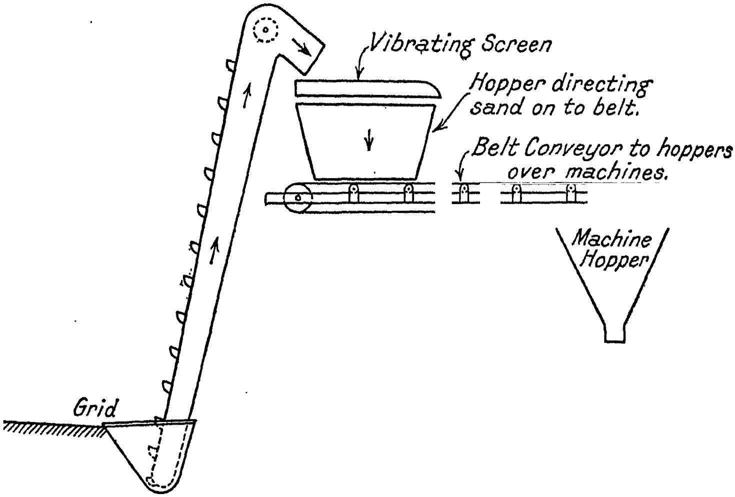

Vibrating Screen
Hopper directing sand on to belt.
Belt Conveyor to hoppers over machines.
Machine Hopper
Grid

FIG. 76.—SAND-MIXING AND CONVEYING PLANT, SUITABLE FOR A NUMBER OF MACHINES

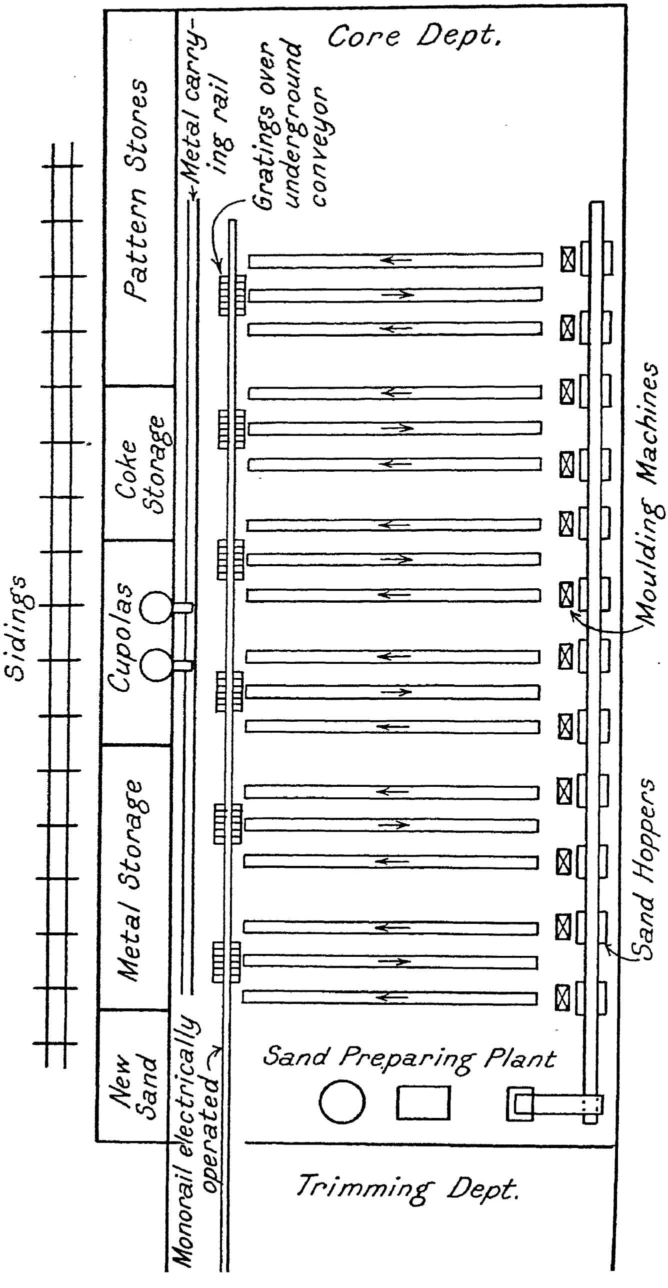


Fig. 77.—Suggested Lay-out of a Machine Foundry engaged on Small Repetition Work

end, the empty boxes returning by another conveyor, situated between two casting lines, and thus serving to return boxes for two machines. The sand is taken to the mixing plant by an underground conveyor, while an overhead belt conveyor delivers the prepared sand to the line of hoppers over the machines. An overhead runway carries the castings to the trimming shop.

General Handling Problems. These few suggestions on lay-out and sand preparation are only intended to illustrate the general principles involved, for no hard and fast rules can be laid down, since each individual foundry—even when the work is of the "jobbing" variety—has its special problems. Because it is usually the material of greatest bulk and weight, the handling of sand constitutes an important problem, the chief consideration being that of reducing to a minimum the amount of labour involved. Success depends upon the following: (*a*) Suitable location of the sand-mixing plant in relation to shop lay-out; (*b*) Arrangement of new sand bunkers to facilitate loading of mixing plant; (*c*) Method of delivering mixed sand to moulding floor bins or hoppers, and (*d*) Method of returning old sand to mixing plant.

Next in importance is the handling of the raw materials charged into the cupola. Apart from the use of mechanical charging, much can be done here by a well-considered lay-out of the stacking ground, in relation to the receiving of the materials, the weight and bulk of each which is used, position of weighing machines and arrangement of charging platform. Other important matters are the handling of liquid metal, moulding boxes, rough castings and returned metal. Where large cores have to be handled, the location of the core-making department in relation to the drying stoves, and to the moulding floor where the finished cores are used, needs careful attention. These various problems must be studied not only in respect of the individual handling operation but also from the viewpoint of the works production as a whole.

CHAPTER VI

MOULDING AND RUNNING IN RELATION TO DESIGN

The operations of ramming, venting, gating, etc., play an important part in deciding the soundness of a casting, and must now be considered in detail.

Ramming. In this operation, the sand is packed round the pattern to form the mould, the ideal density being that which consolidates the sand sufficiently to maintain its shape under the pressure of the metal, but does not make it so hard as to be impermeable. Many types of mould—as a small one, whose inside shape is spherical—can be rammed very hard, however, without prejudicial results. On the other hand, only a slight excess of hardness in the neighbourhood of A in the mould in Fig. 78 will lead almost certainly to trouble. On pouring, the projection at A becomes nearly

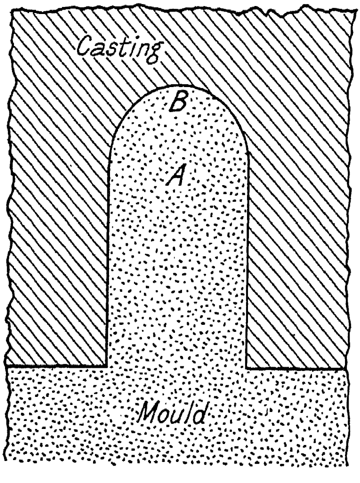


FIG. 78.—MOULD PROJECTION REQUIRING CARE IN RAMMING

as hot as the metal, the air in the pores increasing greatly in volume. Unless it can escape quickly from the mould face, the internal pressure causes the surface sand—now weaker and more friable from the temperature—to lift or scab off, floating into the metal, when a spoilt casting may be the result. Therefore, mould parts which project, or have convex or raised surfaces, must not be rammed too hard, particularly in greensand moulding, or the metal will not rest quietly upon them.

Fig. 78 shows a further complication, for the metal must first flow round the base. Thus, before the metal reaches B, a pressure has been set up making it necessary for the sand to be sufficiently porous to act as a safety-valve, releasing air into the space above. When the top is entirely covered, a large volume of gas has still to escape *via* the base. Thus such parts must be moulded fairly loosely, when the air passages will be as large as possible. When the porosity of the face is reduced by sleeking, coating with plumbago, or, in dry-sand moulding, by wet blacking, it is at the same time made more resistant to air pressure. Contact with molten metal destroys the bond, however, the sand becoming more porous, friable and more readily lifted by pressure. The hydrostatic pressure exerted by metal lying against a mould face is not sufficient to resist the internal air pressure tending to produce a scab, and, in practice, the volume of gas forced into the liquid metal may be so great as to cause it to be violently ejected from runners and risers. When the mould face has been once covered and made friable, any temporary blowing-away of the metal is likely to cause a scab. Shallow moulds need not be rammed hard, the head pressure being low, but, to avoid local swelling, the ramming must be even, particularly for flat plates made in greensand. With increasing depth, one must ram progressively harder towards the bottom, the ramming being applied, however, to the backing and not to the facing sand, if scabbing is to be avoided. The rammer should be kept from 1 to 1½ in. away from the pattern when ramming the vertical walls. The accidental striking of the pattern through the facing sand may be responsible, particularly in greensand work, for a hollow scab at this place in the casting. The loss of permeability of the backing sand caused by the close packing must be restored by artificial venting (see p. 122).

Except for a large job with a lot of sand round its base, patterns rammed in boxes require nothing but hard ramming to avoid distortion, the sides of the box preventing the mould walls being pushed back. Where large deep jobs are bedded in the foundry floor, with no surrounding metal casing, the problem is difficult, and, with jobs from 4 feet in depth, and over, one cannot depend upon ramming alone, and further reinforcement is necessary. After the pattern has been bedded in, and about 2 in. of sand has been rammed hard round the bottom of the vertical face, a shallow trench is cut with a spade all round and about 3 in. from the pattern, pieces of pig iron being laid in it, close together, and bedded down hard with a sledge hammer. Heavy jobs of 7 or 8 feet deep should be moulded in a cast iron casing bedded in the foundry floor, or some distortion is inevitable, being frequently shown after casting by the diagonal cracks in the floor, running away from the top part box. If the metal is prevented from forcing its way into the floor from the bottom edge of the mould, where the pressure is greatest, the consequences may not be serious, but the wall thickness of the casting is greater. A suitable shallow box part, if available, may be dropped into the pit dug out for bedding-in the pattern, so that it stands at least a few inches up the sides of the mould. For deep castings, as condenser bodies, the ring illustrated in Fig. 107 may be used. Here a plate or stout core-iron, having a row of dabbers round the outside, is bedded down in the pit so that the bottom edge of the pattern stands inside the dabbers. Cope parts in general may be rammed much harder than drag parts, this being also necessary, to keep the sand from falling out when they are lifted. Parts which hang from the top, as in Fig. 78, can be rammed firmly. On casting, the metal comes first into contact with the part at B, which, when in the cope, is in the reverse position to that shown, the gases escaping upwards, this natural direction for the rapid removal of gas being maintained throughout the cast. There is an additional advantage with copes, for further avenues of escape are afforded along the sides of the lifters, box bars or other supports used.

Venting. This is an artificial means of imparting to rammed sand the necessary permeability, the cores or moulds being provided with channels through which the expanded air and gases can be readily removed. Those parts requiring careful ramming will need more venting, and surfaces which can be rammed hard without ill effects seldom need venting. Moulds for small pipes, valves and castings of similar shape, whose patterns leave a hollow surface in the mould, do not require venting. Large moulds of this shape have less curvature, and there is more danger of scabbing. When the mould surface is convex or similarly raised, there is great danger. Most cores have such contours and it is essential that they shall pass the air away rapidly. The relative differences in venting a convex and a concave surface are illustrated in Fig. 79 (*a*). When the metal fills the lower part of No. 1 mould, the gases strike back into the sand in the directions of the arrows, and, being cooled by contact with the sand, are correspondingly reduced in volume, escape being facilitated. In mould No. 2, the avenue for gas removal is more restricted, the sand is heated to a greater extent, and the gas must travel further before its volume is reduced, by contact with the sand, to the same extent. When moulds are being rammed up, it is thus

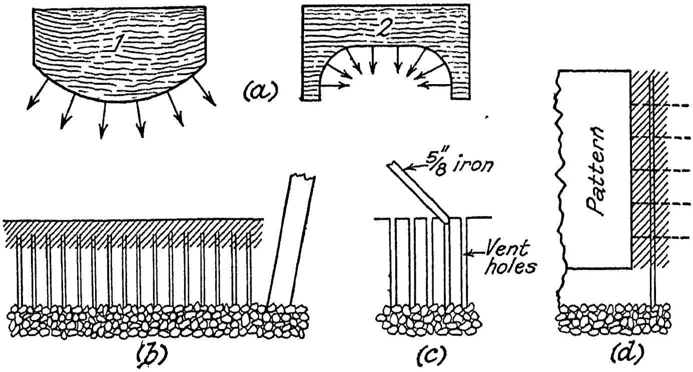


Fig. 79.—(*a*) Mould Faces showing Difficult and Ready Escape of Gases, respectively; (*b*) Arrangement of Cinder Bed, showing Venting; (*c*) Method of Closing Vents on Face; (*d*) Side Venting of Large Greensand Moulds

particularly necessary to provide effective venting for all surfaces liable to scab, a vent wire $\frac{1}{8}$ or $\frac{3}{16}$ in. in diameter being suitable for small work. Greensand needs more venting than dry-sand, because wet sand is less permeable and the conversion of water into steam by contact with hot metal causes an increase in volume in the ratio of 1400 : 1. The moisture content of greensand facings must thus be kept as low as possible. With dry-sand moulds, surfaces liable to give trouble must be sufficiently dried, or the steam pressure may affect the venting, and lead to scabbing. Much experience is necessary to decide if a mould is dry enough, and there are various methods of testing this. The surface may be tapped with a trowel handle, when, if the mould is not dry, it is softer, less sound being produced. On trying to push into the mould a sharp cleaner or pocket knife, little or no impression is made on a dry surface, but the knife will penetrate readily if wet. For large dry-sand moulds, drying must be much deeper, and it is advisable to drill a small hole, so as to measure the depth of dried sand from the surface. The degree of drying necessary for safe casting varies, as ramming and venting, with the shape and size of the mould. Large flat surfaces should be dried to a depth of at least 1 in., preferably $1\frac{1}{2}$ in., while, if the mould has to stand for some time after drying, before casting, the depth of dried sand from the face must be still greater. The bottoms of flanges or ribs, or the mould corners, need not be dried so thoroughly, however, $\frac{1}{2}$ in. or even less being sufficient, because scabs occur less readily here. Small parts of a mould which project into the metal require thorough drying. In general, copes need less drying than drags, and, in loading on the stove carriage, one must have the drag above the cope, to ensure this.

When the drag-half mould is rammed up by turning over from a board or odd-side, one usually vents by pushing a straight wire from the bottom of the box through the sand to near the pattern face, just before turning over. In small boxes, the vents are led away from under the box by pushing a vent wire underneath, after it has been put down in its casting position. With large moulds, the box is first placed on the bed in the casting position, this consolidating the bed.

It is then lifted off, and a series of small channels are made all across the bed by repeatedly dropping on to it the long handle of a rammer, the box being again lowered on to the bed. The venting of the under-side of a mould bedded in the floor is more difficult. Comparatively small moulds, and those larger ones having free-venting surfaces, can usually be vented well enough by pushing a vent wire from the joint, underneath the pattern, just before this is drawn out of the mould. A curved wire is used, to get nearer to the bottom face. When ramming large moulds by the bedding-in method, and also with smaller ones, if the bottom face presents venting difficulties, a cinder bed is laid under the pattern, vents being pushed down from the mould face into this. If the mould is to be dried, the bed may be about 6 in. below the mould face, but, for a large greensand mould, the bed should be 12 in. below. If placed too near, the mould may be so strained as to cause metal to run down into the bed. A bed of cinders or clinkers about 3 in. deep will be suitable for most jobs, the larger pieces being broken up somewhat, while any smalls passing a ½-in. sieve are rejected. Before putting in the cinders, the bottom of the pit is consolidated by a flat rammer, the filled-in cinders being compacted by lightly flat-ramming, while one or more vent pipes are run up from the cinders to the level of the top joint face of the mould, the arrangement being shown on the right of Fig. 79 (*b*). A good cinder connection must be made at the bottom of the pipe, and the atmospheric end must be stopped up, to prevent sand from falling down into the vent; the stop being removed before casting. The bottoms of dry-sand moulds are usually vented after the facing sand has been rammed on. When a flat bed is made, by means of straight-edges, in order to receive the pattern, the bed is vented just before the pattern is put on, but, when the pattern is placed in the pit and the bottom shape is formed by ramming sand up to it, the venting is often left until after the pattern has been removed for finishing. In either case, one vents down to the cinders with a wire about ⅜ in. in diameter, knobbed slightly at the end, for ease of working, stopping the holes on the face by ramming a small piece of rod obliquely across the top, much as shown in

Fig. 79 (*c*). The vents are spaced about 1½ in. apart, the cavities resulting from "stopping-up" being afterwards made good with facing sand. When a cinder-bed is used under a comparatively shallow dry-sand mould, it can be put much nearer, say, 3 to 4 in. from the face, a vent of smaller diameter being used, and a lesser disturbance of the mould face resulting.

The venting of the bottom face of a large greensand mould requires much care. The main vents are pushed down to the bed before the facing sand is put on, and closed as seen in Fig. 79 (*c*). After the pattern has been withdrawn, the 1 in. of facing sand, put on after venting, is "needle-wired" very closely at an oblique angle, as shown in Fig. 79 (*b*), most of the needle vents, made with a wire about $\frac{1}{16}$ in. in diameter, thus cutting across the main vents, so as to ensure a direct passage for the gases from the mould face to the cinder bed. The sides of greensand moulds are vented progressively during ramming. After each layer has been rammed round the pattern, a small wire, about $\frac{5}{16}$ in. in diameter, is pushed into the sand near the face at an angle of about 45° to the face of the pattern. On reaching the joint, a large vent-wire is pushed down, all round the pattern and at a distance of about 1½ to 2 in. away from it, as far as the cinder-bed, so as to link up all the small vents, and carry them down to the cinder-bed, as seen in Fig. 79 (*d*). For the sides of dry-sand moulds, only the main vents are necessary.

Sprigging. Face-sprigging is used to prevent the metal from scabbing the face of the mould, and consists of reinforcing the surface by pushing in moulder's sprigs or brads, usually during the finishing operation. Sprigs 2 in. long are generally used, longer ones being necessary near to a mould edge or corner, this, however, being not only to protect the face, but also to support the corner. If the surface appearance of a greensand casting is important, the sprigs should be pushed down until they are about $\frac{1}{32}$ in. below the face. If they are merely pushed down with the trowel so as to be level with the face, small impressions will be left on the casting, where the sand has been forced back slightly under the pressure of the metal. In dry-sand moulds, it is unnecessary to push the sprigs below the surface, the mould face after drying being more resistant. Also, the face of a dry-sand mould, after sprigging, is always given a coating of wet blacking, which is thicker than the layer which is rubbed or dusted on greensand moulds, and serves to cover up the sprigs. One can generally see, by a sort of shading effect, where dry-sand moulds have been face-sprigged, but this is obliterated when the castings receive their final coat of paint, for service. The parts requiring face-sprigging are nearly always those that have to be well vented. A different application of this process is seen in a massive casting where the cope has a large surface area. In such a mould parts of the cope face are exposed to an intense heat for a relatively lengthy period before the metal flows up to them, so that the sand grains expand, cracks may develop, and pieces may even fall away, the effect being known as "drawing down the cope." Sprigs are much used to prevent these effects, and, where the danger is great, should be set very closely, at say ½-in. intervals. If the cope has not been closely liftered, longer sprigs should be used, to increase the support afforded to the sand. Even when the cope is face-sprigged closely, it would be impossible, in many moulds having large surfaces, to keep up the copes, if it were not for the air pressure inside the mould, resulting from its rapid filling with metal. When the danger is still thought to exist, the risers are very tightly closed, and the pouring speed is increased, so that the necessary pressure may be maintained.

Sprigging is also used for reinforcing the sand face near where the runner enters the mould, particularly when this is not situated at the extreme bottom, when the metal consequently flows considerably further laterally before the mould is filled; where, therefore, the risk of the erosion of surface sand is greater. This method of running is not a good one, but, where it cannot be avoided, sprigging the face will help a good deal in preventing erosion. Another method is to nail upon the mould face a piece of thin tinned iron, to receive the first assault of the metal. Alternatively, very short pipe nails may be knocked in, so that the heads are very close together. A very effective method is to place against the pattern face, when ramming up the mould, a core previously coated with tar and dried. Time spent in considering the subjects of ramming, venting and sprigging will be repaid many times over. It is of course possible to lose time on medium and large work by paying too much attention to these operations when dealing with mould parts almost immune from trouble; but a large number of defective castings are due to a lack of knowledge of the principles in question. It is most valuable, also, to examine as many castings as possible, as soon as the sand has been stripped from them, or, preferably, just after sand-blasting, for this enables one to judge, when looking at a pattern, the safe minimum amount of work that must be expended in moulding —an extremely valuable asset, yet one which some foundrymen seem never to acquire.

Gating. By gating, one understands the determination of the size, shape, position and number of runner and riser gates necessary for correct casting. Gating is always important, but it is of paramount importance in general work, because, if, as often, only one casting is required from a particular pattern, it is out of the question to establish the correct method of gating by a process of trial and error. Although risers often play an important part, the fixing of the runners, on anything but the simplest work, demands greater experience. Many shrinkage defects are due to varying rates of solidification in different parts of the casting, and the positioning of the gates can often be made to equalise cooling in the different sections. This is always an advantage, but often cannot be achieved by gating, when the in-gate may be used instead—as with many small non-ferrous castings—to provide a reservoir of liquid metal, so that the casting may be fed during solidification, which is thus deliberately delayed at the junction of the in-gate and the casting. This method has, however, only a limited application for cast iron.

The size of a runner gate depends on the volume and temperature of the metal passed through it, the area of the mould surface, and, with certain massive castings, the time taken to fill the mould. The position of the gates depends on the type of casting. Small castings can generally be run by cutting the in-gates in the joint, but for most large ones the gate must be at or near to the bottom. The shape of the runner is often determined by the section of the casting where it enters. A round gate will pass more metal than a gate of equal sectional area of any other shape, because it has minimum surface friction. Round gates are specially suitable for greensand work, because they stand up to the wash of the metal better than rectangular ones. Many jobs can be run with top-gates, the metal falling direct from the runner-bush into the mould. This is the simplest type of runner, for it is only necessary to ram up the runner sticks on the pattern when ramming up the cope. Top-gates are chiefly suitable for jobs where the metal falling through the gates drops directly into the mould bottom, and a reservoir of metal can quickly collect, to serve as a cushion for the remainder. They cannot be used for deep greensand work, because of the erosive action of the metal when falling from a height. They may be used, however, for running long cylindrical castings made on end in dry-sand and loam, when one nearly always uses several small gates at intervals round the top of the cylinder. For special work, a number of small gates are preferable to one large one, because there is less difficulty in preventing dirt from entering the gates from the runner-bush. For castings which are machined on the inside, the gates should drop down near the outside of the mould, and, if there is only outside machining, should be kept near to the core. Any dirt entering with the metal tends to attach itself to the surface nearest where the metal impinges, as shown diagrammatically in Fig. 80, representing

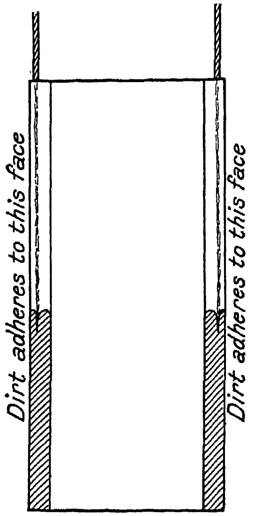


FIG. 80.—SECTION THROUGH HALF-FILLED MOULD FOR LINER

a section through a partly-run liner casting. When both sides are machined, the gates may either be dropped centrally, or close to the outside, which is the least important face in liners. When the liners are rammed on end, the gates can be put in any position desired, but, when ramming horizontally and turning on end for casting, special arrangements are necessary. When running near to the inside face, the pattern and core-box are made as usual, and a circular connecting gate is placed round the core print joining the main down-gate, A, in Fig. 81 (*a*), to the small in-gates, B. When it is desired to keep the small in-gates close to the outside of the liner, the pattern is made as a straight barrel, its length being determined by the core, which is made the diameter of the pattern at the runner end. The circular trench and small in-gates are then fixed in the core-box, and, when the core is lowered into the mould, the in-gates are in the positions indicated by the dotted lines in Fig. 81 (*b*).

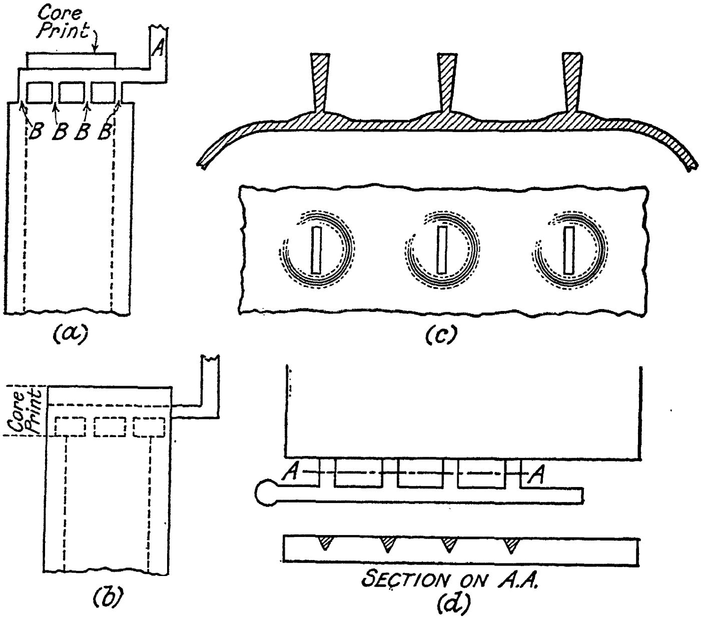


Fig. 81.—(*a*) Arrangement for Running Liner close to Centre Core; (*b*) Arrangement for Running Liner near Outside Wall; (*c*) Gates used for Bath Castings; (*d*) V-shaped Spray Gates

cast from a common down-gate. The semi-circular in-gates are known as " horn-gates," and, being tapered, are readily removed from the sand by tapping the small end, afterwards withdrawing them by a circular movement from the large end. Fountain runners, as in Fig. 84 (*b*), are used for bottom-running castings whose design makes them difficult to run from round the outside. Unless a bottom joint is used, the in-gate is removed by digging away behind the down-gate, and then drawing it backwards into the hole. So that the metal shall enter quietly, A should be 1½ times as great as B. Whenever bottom-pouring is used, the down-gate should extend, as at C, a little below the in-gate, when it helps to trap any dirt which may have fallen down the gate while closing. Clean and carefully made runners are essential for important work, but there is always the possibility of dirt

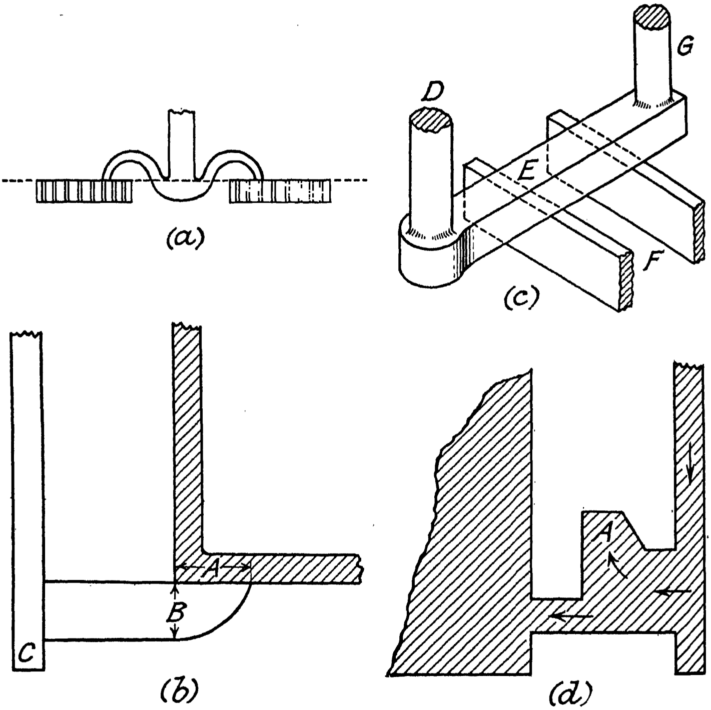


Fig. 84.—(*a*) Horn Gates; (*b*) Fountain Runner; (*c*) Gating through Top Trench; (*d*) Trap Runner

entering the mould, especially when pouring large quantities of metal. Such dirt will nearly always be found in the casting in close proximity to the runner. A number of devices are used to avoid such inclusions, most of these taking advantage of the lower specific gravity of the non-metallic matter, which is caused to float to the top of the metal, the mould being filled from a lower level. One of the simplest methods, the top-trench, is illustrated in Fig. 84 (*c*). The metal enters by the down-gate, D, flows along the top-trench, E, and is then fed into the mould through the in-gates, F. Any dross should be held in the top-trench, which, being cut in the cope, is above the mould joint, the in-gate being in the drag part. A riser is occasionally put on to the end of the trench, and taken up through the cope, as shown at G. When care is used, it is only the first rush of metal down the gate which carries down any dirt, and this explains the efficacy of the top-trench, because the first metal to enter the gate flows

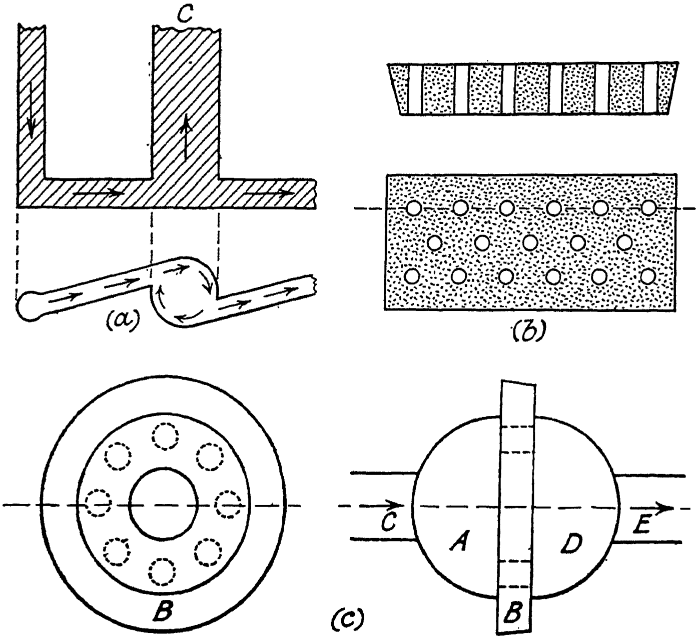


FIG. 85.—(*a*) SPINNER GATE; (*b*) CORE FOR FILTER RUNNER; (*c*) SPECIAL FILTER GATE

right across the in-gates in the drag, the dirt being carried right to the end of the trench, where it flows up the riser. The runner arrangement in Fig. 49 (*a*) resembles that of the top-trench, because the extensions on the horizontal portion are designed to trap the first metal. The spinner-gate, another useful runner chiefly applicable to small work, is shown in Fig. 85 (*a*). As the metal passes down the gate, it enters the spinner A at a tangent, circling in the direction of the arrows, any dirt rising up the column C and allowing clean metal to enter the mould from the bottom. The spinner is sometimes taken right up through the cope to the level of the runner-bush. Fig. 85 (*b*) illustrates filter-runners, where a dried core, perforated with small holes, fits into the top of a special down-gate, with a tapered upper end. The runner bush is set round the core, and the metal drains through the small holes before entering the gate. The operation of filter-runners as a dirt trap is not entirely due to the holes being too small to pass any dirt, but also to a different reason. The down-gate is drawing metal, through a number of small feeders, from a comparatively large area, the metal in the bush thus remaining very steady, with an entire absence of the swirl so often seen in other runner bushes, the dross thus floating on top, instead of being dragged down into the mould. A modification of the filter-core, shown in Fig. 85 (*c*), is used for many jobs rammed horizontally from split patterns, and turned on end to cast. It consists of a spherical pattern, A, split along the dotted line, and having a core print, B, running round its periphery. The filter pattern is rammed in the joint when the pattern is rammed up, so that the down-gate flows into the end of the sphere at C. Before closing, a perforated half-circular core is fixed in the print B in the drag half and a similar one in the cope. On closing, the two half cores come together. In casting, the metal enters the small reservoir at A, flows through the small holes in the two half cores into the lower half of the sphere D, and then passes, *via* the lower part of the down-gate, E, on to the in-gate. Ronceray's system consists in passing the metal through a pencil-runner, of some $\frac{1}{4}$ or $\frac{5}{16}$ in. in diameter, the metal entering the mould so slowly that the primary shrinkage takes place as the mould is filled, little or no solidification shrinkage being apparent after the mould is full. Success is only possible by using very hot metal, while the limits of runner-size which will lead to sound castings, neither "short-run" nor drawn, are narrow. With experience, the method can often be used with advantage, enabling rod-feeding to be dispensed with.

Other methods of gating are chiefly modifications of those already described, an instance being the trap-runner, shown in Fig. 84 (*d*), often used on small important castings, moulded on the flat and cast on end. As the metal passes into the mould, any dross rises and remains at A. A method of running large castings involves the use of in-gates at varying levels, the mould being thus more uniformly heated than when bottom-run. Care must be taken to prevent metal from entering an upper gate until the mould has filled nearly to this level, or scabs may result from the metal falling violently down the sides of the mould. This may be avoided by the use of plugs, discussed later. Nor must the higher gates be kept closed too long, or metal rising over them will flow in, solidifying in the narrow in-gate, so that when it is finally unstopped, no metal can enter. When massive castings such as flywheels have to be run very quickly, to prevent the drawing down of the cope, it is better to use a group of gates instead of one or two large ones. There is then less chance of dross or air being sucked down the runner bush. If a casting defective for this reason is broken up, small particles of slag and oxidised iron, associated with small holes caused by gas reactions, will be found in the track of the runner.

Risers. These play an important part in the production of sound castings, but are often expected to accomplish the impossible. Their functions and limitations must be appreciated. The use of a riser tells the caster that the mould is full, and thus promotes clean casting and prevents spilling of metal, for the bush can be kept full without the same danger of overflowing when complete. Risers reduce the strain imposed by the rush of metal as the mould becomes full, and, the larger the area of the runner gates, the more necessary do risers become. If the outside edge of the pattern is not lower than some portion of the central region, it is advisable to place the riser stick just off the edge of the pattern, connecting this to the mould later, when finishing. This method is usually described as "rising off the casting," as distinct from that where it is placed directly on top of the pattern. If the riser is off the casting, less care is necessary in making up the bushes, because, if any dirt should fall down, it remains at the bottom of the gate and cannot get into the mould. In this position, risers are usually a little more effective in preventing strain, because, when the metal strikes the cope, it spreads out laterally, *i.e.*, in the direction of risers off the casting. Risers are placed directly on the pattern for two reasons. When the pattern has a projecting boss, flange or bracket on its upper face, air and gases tend to collect and become entrapped at these high places, and the use of risers on such elevated parts will largely prevent this. Risers on the casting serve also to supply liquid metal to compensate for solidification shrinkage, and, on bosses, flanges or other heavy portions, must be large enough to remain liquid until the parts to which they are attached have solidified, unless some artificial means is employed to prevent this prior solidification (*See* Feeding).

A riser which often obtains more credit than it deserves is the dummy riser, which consists of a small extension, usually on elevated parts of the casting, and made by pushing a tube into the cope in the desired position. Dummy risers are seldom more than 2 in. long, and many are sometimes used on one casting, with the ostensible purpose of acting as cleansers, but their action is purely local, and they are only really effective when they form an almost continuous riser on top of a narrow strip requiring machining, as in Fig. 86. Even then, it is often better to increase the machining allowance as shown by the dotted lines, using one or two straight-through risers, to stop air being trapped in the ring facing. Whistlers are diminutive risers, put on thin parts of castings projecting into the cope, and made by pushing through a cleaner or vent wire.

On medium and large work, risers are usually closed by plugging the top with cotton waste, or similar material, covering this with sand lightly pressed down with the hand. They should be closed tightly enough to stop the waste being blown out by the air pressure during casting, but should not be so tight as to prevent the metal from rising. The main purpose of closing risers is to prevent the drawing down of the cope, as has been described. There is, however, another purpose. When metal begins to flow round the base of a core, the air inside at once rises, causing a pressure in the crown of the core. If there is a high pressure inside the mould, and thus outside the core, it helps to make the core gases escape through their proper channels, instead of through the top of the core. In the latter event, scabbing may ensue as soon as the metal begins to wash over the top of the core. If there is no danger of bringing down the cope, or of cores scabbing, there is no objection, however, to leaving risers open; indeed, on this light work, it may be advantageous, the lower pressure in the mould offering less resistance to the entering metal, and making "cold-shuts" and "short runs" less possible.

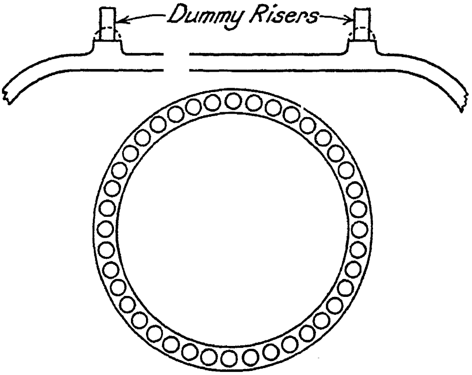


FIG. 86.—ARRANGEMENT OF DUMMY RISERS

Runner Bushes are generally of cast iron, lined with sand, and are placed over the top of the runner gates to receive the metal from the ladle. By pouring rapidly, a reservoir of metal is formed in the bush, so that dirt is prevented from entering the mould, and instead, remains on top, clean metal being fed into the gate from the bottom. Small bushes for moulds poured with a hand shank are usually circular in shape. The down-gate should be located near the side, for, if in the centre, the metal may swirl, and dirt may enter. The bush, when in position, should be fingered round the bottom inside edge, to stop leakage from under the bush. If only a few are wanted, they are "made-up" by wetting the inside of the bush, putting it on a flat board, and squeezing sand round the inside with the fingers. For larger quantities, a cast iron block is laid on the flat board, and the bush put round it, as in Fig. 87 (*a*). Sand is thrown hard into the space between block and bush, the surplus is scraped off with the trowel, the block is sharply tapped and the bush is lifted off. For mass production, one may use a machine, some of these squeezing up the bushes very rapidly. When pouring from a crane ladle, rectangular bushes are better, the flow of metal being steadier. The plain rectangular bush, as in Fig 87 (*b*), is made up as follows.

A is a small well to receive the first fall of metal and prevent splashing; while B is the entrance to the down-gate. Fig. 87 (*c*) is a badly made bush, leading to splashing, as indicated by the arrows. If the bush is made up on the cope, before closing on to the drag, no dirt can be dropped down the gate. In this case, the bush can be wet-blacked and skin-dried with a bucket-fire, if desired. Loam runner bushes, generally used for large work, consist of a cast iron plate, with a row of dabbers round the outside edge, and a suitable hole, considerably larger than the down-gate it is desired to feed. The plate is lined with bricks and loam, which is dried in the stove, the plate being then placed on about 2 in. of soft sand, spread on top of the cope, so that the down-gate pegs stand through the hole in the bottom of the plate. Greensand facing is rammed securely to a depth of about 3 in. all round the runner gates, and smoothed off flat, when the gate pegs are removed. Care must be used when ramming round the top of the gates, or the metal may force its way under the bush in casting. Fig. 87 (*d*) shows the completed bush. There are various modified types, to ensure dirtless running, but, if care be taken, the use of any of these is seldom necessary. Some utilise a filter-core, placed midway, the metal falling on one side being strained through the core into another reservoir, which feeds the gate. Others use a core standing a little off the bottom to divide the bush, the metal passing under this to the gate side, as with a sluice gate partly open, the dirt remaining on the runner side.

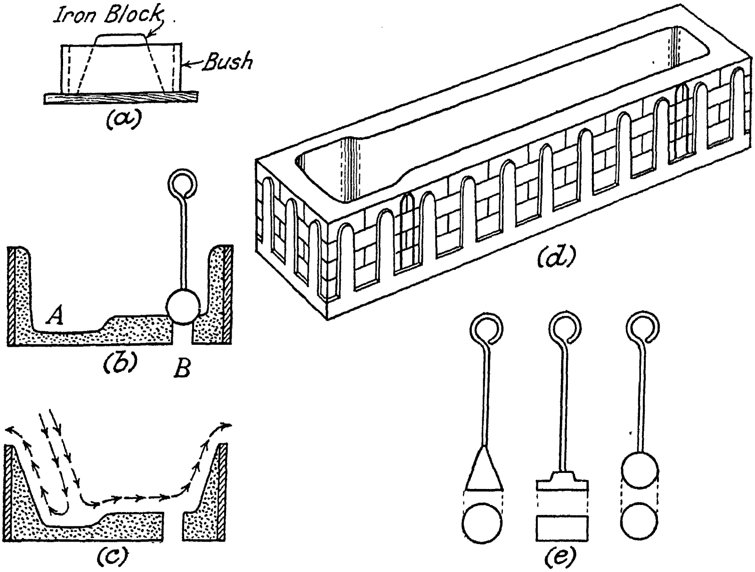


Fig. 87.—(*a*) Method of Lining Runner Bush; (*b*) Correct Method of Making-up Rectangular Runner Bush with Ball Plug Seating; (*c*) Incorrect Method of Lining Rectangular Bush; (*d*) Bricked-up Loam Runner Bush; (*e*) Types of Runner Plugs

Runner Plugs or Stoppers. Plugs are used to cover the down-gates until the bush is filled. Any dross should be skimmed off the ladle before casting, but more scum invariably forms on the first metal to enter the bush. If the gates are plugged until the bush is full, and a steady reserve of metal is maintained in it, dirt floats on the metal and does not enter the down-gate. Types of plug are shown in Fig. 87 (*e*), the usual form consisting of a mild steel handle on which is cast an iron head. Before use, it should be black-washed and dried, this not only preventing explosions due to the molten metal coming into contact with rust or damp, but also increasing the service life. If, after lifting, the plug is held so that the bottom rests on the surface of the liquid metal in the bush, swirling is prevented and cleaner castings obtained. For heavy castings, where the bushes hold large quantities of metal, ball plugs, as in Fig. 87 (*b*), are preferable, not only making a more effective seal, but also tending to damage the sand at the gates to a much less extent than with flat-bottomed ones. Where, as with high-level gates, plugs have to remain for a longer period in the metal, the stems must be given a thin coating of stiff loam, and afterwards dried, to prevent their being melted by the metal.

Shrinkage Effects. The question of shrinkage is discussed more fully later (see p. 214), and we are here concerned only with the effects, particularly those due to the just solid metal occupying a smaller volume than when liquid, the difference being solidification shrinkage. In the more massive parts of castings, the effects often take the form of piping towards the middle, at or near the top, as illustrated diagrammatically in Fig. 88. The average foundry casting is not of the plain massive type, however, consisting more usually of one or more metal walls, with bosses, ribs, flanges, etc., attached, when the shrinkage causes internal cavities or spongy areas, commonly termed draws. Cavities so produced can be recognised by their rough internal surfaces, crystal dendrites being often seen projecting from the adjacent metal into the

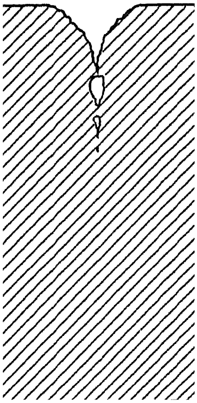


FIG. 88.—THE EFFECT OF SHRINKAGE IN A MASSIVE CASTING, GIVING RISE TO PIPING

cavity, like numerous diminutive stalactites. Blow-holes due to gases being trapped have, on the other hand, smooth shiny surfaces, often with an oxidised bluish appearance. As the metal cools, heat is lost from the outside, solidification occurring progressively from the mould surface to the middle of the casting, where, unless means have been provided for feeding down more molten metal to make up for the shrinkage, cavities may naturally be found. There may be no actual cavity, but the crystals may be so loosely packed, or porous, as to lead to failure under the hydraulic test. In a casting of varying section, the prior solidification of a thinner portion may often close up the channels by which more liquid metal should be supplied, thus causing a draw. The matter is further complicated by the fact that thinner parts of the casting have solidified and are contracting, while adjacent heavier portions are still solidifying, when there is a greater likelihood of the metal being unsound. The methods of avoiding these defects will be discussed in some detail.

Feeding Heads. These are used on most jobs cast vertically, if required to be highly machined and to withstand hydraulic pressure, *e.g.*, Diesel and steam engine liners, rolls, hydraulic cylinders, large condenser shell castings, large steam cylinders and the like. The feeder head is an extension to the upper end of the casting, by means of which the necessary supply of liquid metal and the soundness of the casting are ensured. The head itself is almost invariably unsound, but, as this is waste material, afterwards machined off, this is of no consequence. Extra metal, apart from the machining allowance, is occasionally used on castings where drawing is unlikely but which may be otherwise unsound. In the plain parallel liner shown in Fig. 89 (*a*), unless 2 or 3 in. of head is provided, the top edge might be dirty after machining, from the dross floating up on the metal as it rises in the mould. The usual type of head is shown at Fig. 89 (*b*), and tapers outwards, so as to increase the mass, and prolong the period of solidification towards the top, thus raising the "hot spot" above the dotted line, the top of the actual casting. Parallel heads may be used, but must be deeper than those which taper outwards. The bulbous head (Fig. 89 (c)), enables one to make a small reduction in the quantity of head metal, but there is usually an increased time for moulding. The type shown at Fig 89 (d) also saves metal, and facilitates the removal of the head, by reducing the depth of cut at C. There are two essential requirements if this design is to be successful. To keep open the passage between the head and the flange, so as to avoid a spongy spot at D, the dimension *x* must be at least 20 per cent. greater than *y*. A good machining allowance is required at C, for the removal of holes due to trapped gases. Unless the dimensions of the casting are known, one cannot say how much head is required, but one can seldom use one of less than 8 in., and as much as 18 in. may be necessary. For a small number of castings, it is better to err on the generous side. For large quantities, experiments can be made to find how much the head can be shortened. One must part it off each time and note the result before reducing further. When bosses or other heavy masses come near the top of a casting, a large riser placed over each will serve as a feeding head. If this riser is to be self-feeding, it must be made large enough not to solidify before that part of the casting which it is to feed.

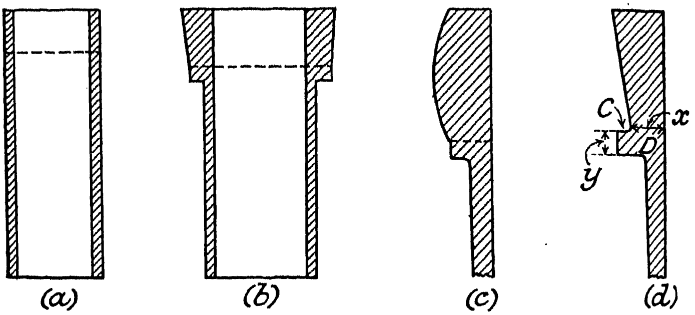


FIG. 89.—VARYING TYPES OF HEAD FOR LINERS, AND OTHER CYLINDRICAL CASTINGS: (*a*) PARALLEL HEAD; (*b*) TAPER HEAD FOR FLANGED LINER; (*c*) BULBOUS HEAD; (*d*) SPECIAL HEAD

Rod Feeding. This is the moving up and down, through the gate into the casting, of a wrought iron or mild steel rod, until the metal has set. Solidification of the metal in the gate is thus retarded and allows the metal in the bush to feed down into the casting. The rod should be heated in the ladle, and, for a small job, is put into the riser or runner gate, usually the former, as soon as the mould is full. It is pushed down until it touches the bottom of the mould, and then raised again, so that its lower end is not more than 2 or 3 in. in the casting, being thus slowly worked up and down, and at the same time moved gradually round the periphery of the gate, so as to keep open as large a passage as possible for as long as one can. Success in rod feeding depends entirely upon the moulder, for careless movements of the rod when the metal is becoming pasty will cause spongy places under the gate. As soon as the viscosity of the metal prevents the rod being moved freely, the mean height of the rod is gradually raised, so that the bottom of the rod is slowly brought up and out of the casting, and up the gate, as the metal becomes solid beneath it. Risers for rod feeding can be made smaller, so as to be readily removed on trimming, while self-feeding risers must often be so large that mechanical means are required for their removal. Rod feeding is the only economical method of avoiding defects due to solidification shrinkage in such massive castings as flywheels, hammer-blocks, etc. For this class of work, the risers must be from 5 to 9 in. in diameter, varying with the weight of the casting, and as few in number as possible. One only may be used either on a hammer-block or a flywheel of small diameter. For large flywheels, two should be used, diametrically opposed to each other, so as to preserve the balance when on the shaft. Large risers, which may feed for a period of ½ to 4 hours, varying with the mass, should be covered with blacking, and left for a time before rod feeding is started. One tries with a rod occasionally, and, as soon as the pasty stage begins, the stiff metal in the bush should be skimmed off, a little hot metal added, and feeding begun. More metal must be added periodically to the feeding-bush on all large jobs, and even on some smaller ones, to keep the metal from freezing over. A few pounds of hot metal added frequently are more efficacious than a larger quantity less often.

Denseners (or Chills). The use of denseners, or, as they are often called, chills, is one method of preventing shrinkage troubles. Denseners are small pieces of iron, shaped to fit against the pattern where comparatively heavy masses occur, being usually located in position as the mould is being rammed up, and left behind, after the removal of the pattern, so as to form part of the mould face. The iron, having a heat conductivity much greater than that of sand, absorbs heat much more rapidly from the thicker portion, accelerating solidification considerably. One or two examples of the uses of denseners should be useful.

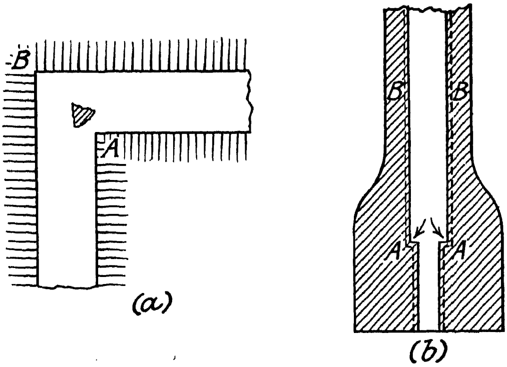


FIG. 90.—(*a*) ANGLE OF CASTING, WHERE THE SHADED PORTION INDICATES THAT WHICH IS LAST TO SOLIDIFY; (*b*) SECTION THROUGH CIRCULAR CASTING LIABLE TO SHRINKAGE DEFECTS

As soon as molten metal comes into contact with the mould, a thin skin of sand on the face becomes heated almost at once to the metal temperature, a little heat being lost by the metal at the same time, in heating up the mould skin. Although sand is a poor conductor, the heat slowly penetrates from the mould face back into the sand, the metal continuing to lose temperature to a corresponding degree. In the casting with a right-angled corner shown in Fig. 90 (*a*), if the mould is of even temperature, the effect of the skin will, as regards heat absorption, be much the same all over, but conduction is much retarded at the inside angle A, where the streams of heat from the two adjoining faces cross each other, this part of the mould being therefore more quickly heated to the metal temperature. In the two surfaces meeting at B, no such difficulty arises. The metal last to solidify must be therefore much nearer to A than to B, as indicated by the shaded area. Fig. 90 (*b*) shows a circular casting, with a hole cast in the centre, where shrinkage defects may be serious. Directly after casting, the lower end of the core, with its small mass, becomes heated to the metal temperature, and little cooling occurs on the inside, solidification proceeding almost entirely from the outer surface. This slow cooling of the interior results in a "hot spot" all round the core, as indicated by AA. The earlier freezing of the thin wall BB prevents any metal being fed down from above, and, when the casting is machined inside, as shown by the dotted lines, a shrinkage cavity will almost certainly be exposed in the corner marked with the arrows.

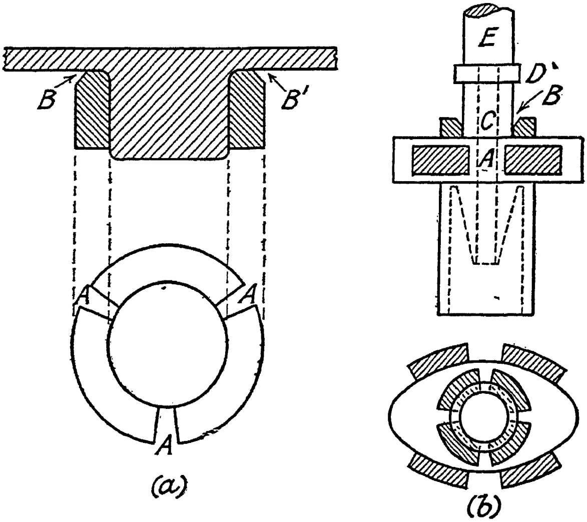


FIG. 91.—(*a*) USE OF DENSENERS ON HEAVY BOSS; (*b*) DENSENERS EMPLOYED IN CASTING A DIESEL ENGINE EXHAUST VALVE CASING

Fig. 91 (*a*) shows a simple method of applying denseners, shown shaded. Three pieces are used, as being more readily fitted to the pattern, the spaces left at AAA being filled with sand. The lesser thickness at BB′ reduces the cooling effect at the ends, where the thickness of the casting becomes smaller. Denseners are used, in the example shown in Fig. 91 (*b*), to prevent the effects of liquid shrinkage in the bore near to A. The upper portion of the stem is increased in diameter to allow metal to feed down from the riser E. The denseners are cut away round the neck at B to stop solidification of metal at C before the metal at A freezes. The collar D indicates where the riser E must be cut off. Denseners must not be too massive, or they may cool the metal so rapidly as to prevent the separation of graphite, the casting being locally hard and unmachinable. In this case the densener is acting as a chill, which is not its proper function, this effect being known in grey iron practice as " over-chilling." The possibilities of over-chilling depend much on the composition of the metal. If it is soft, with a silicon content of about 2 per cent., the margin is wide, and there is little danger of this occurring. In cylinder irons, however, where the silicon content may be only 1·1 or 1·2 per cent., the margin is much narrower, and, unless one has considerable experience, one should test the effect of denseners of varying thickness on a small plain casting of the same thickness as that on which the denseners are to be used. The test casting is broken up and examined for chill, before deciding on the size of the denseners to be used on the actual casting. Denseners must be clean and free from rust. When used in greensand moulds, moisture may condense on them, a dressing of oil and plumbago being used as a preventative. In dry-sand moulds, they should be cleaned after the mould is dried, and given a coating of blacking while still warm. The cast iron for denseners should have a low phosphorus content, or the melting point may be so low as to cause them to fuse on to the casting. On light and medium work, they can be used many times over, but, for a heavy mass, they should not be used more than two or three times, or the face of the casting just under the densener may be covered with small blow-holes. A method of locally accelerating solidification having some application is the casting of horseshoe nails in the metal. The points of the nails are pushed into the mould face just before closing, so that the heads stand well into the metal on casting, and it is then slightly cooled by them. This method is useful for setting in small bosses, etc., where the nails are afterwards completely removed when the casting is machined, as by the drilling-out of a boss. The strength of the joint between the steel nails and the surrounding metal is probably rather weak, and they cannot be considered satisfactory as an integral part of the casting. For less important castings, the nails may be used in groups, however, even where they are not to be machined out.

Composition in Relation to Solidification Shrinkage. A reduction in the proportions of the two chief fluidising constituents, phosphorus and silicon, shortens the freezing range and reduces the chance of shrinkage cavities, this applying particularly to small and medium castings of fairly heavy section, as shaft couplings, gear wheels and the like. Sufficient phosphorus must be retained to supply the fluidity necessary to avoid gas holes, and the silicon must be sufficient to make the iron grey and machinable. In metal with a short freezing range, the casting tends to sink from the top face, this being corrected by the provision of feeding risers. In castings required to withstand pressure—having usually a relatively thinner and more uniform metal section, with numerous brackets, ribs or flanges—porosity due to solidification shrinkage at the junctions of ribs and flanges is best avoided by the use of an iron with a silicon content of about 1·8 to 2 per cent. If this recommendation does not appear to agree with the above, one must remember that, in such castings, the walls are never very heavy, and the metal sets fairly quickly. The high silicon promotes the separation of free graphite in the just-solid metal, the resulting slight expansion helping to correct the shrinkage. Although silicon is thus of definite advantage, its proportion must not be too great, or the metal will be open-grained and weak.

Solid Contraction. The amount of solid contraction—the pattern-maker's allowance for contraction—depends primarily upon the composition of the metal, but also upon the shape, and therefore upon the varying rate of cooling in different parts of the casting. When great accuracy is necessary, no hard and fast rules can be laid down, but $\frac{1}{10}$ in. per foot is a suitable allowance for the usual cored castings and $\frac{1}{8}$ in.

per foot for thin shells or plates. When cooling is very rapid, as with castings about $\frac{1}{8}$ in. thick, the contraction may be much greater than $\frac{1}{8}$ in., and in castings of heavy mass it may be less than $\frac{1}{10}$ in. per foot. Large castings often contract less in depth than in width and length, and, unless this is allowed for, difficulties may arise in the machine shops. To minimise this tendency, projections such as top and bottom flanges of condenser shells, large pipes cast vertically and similar castings, should be thickened up to the extent of about $\frac{1}{8}$ in. on their back side, where they are spot-faced for the bolt heads in the machine shops. A table giving the usual contraction allowances for various types of casting in different materials is given in an appendix.

Warping and Cambering. Warping is most prevalent in castings which are flat and thin, or are very long, and is due either to inequality in cooling after the casting has become solid, or to a greater resistance to contraction in one part of the casting than in another. In the second case, the resistance must be removed as soon as the casting is solid. Except in very massive castings, solidification is complete before the outside of the moulding box gets warm, but, long before the solid contraction is completed, heat begins to be radiated from the box. As the cope generally contains less sand than the drag, which is resting on the foundry floor, and is thus not exposed to the same extent, radiation is more rapid from the walls of the cope, the upper side of the casting cooling before the lower one. In flat thin castings, the top surface cools only slightly before the other, but the rapid cooling of the outside edge, coupled with the slightly cooler top face, usually makes the corners curl upwards. There are several ways of preventing warping. Where possible, bending the pattern in the opposite direction, or "cambering," is most economical. For repetition work, the necessary degree of camber is generally found by trial. If the camber is insufficient, or where only a few are required—when it is usual to have the pattern straight—the defect must be prevented in another manner. As soon as the casting is solid, the cope is lifted off, and the centre of the plate uncovered, keeping the outside edges well covered with the sand. The middle of the casting is thus enabled to cool and contract at the same rate as the outside. Long and narrow plate castings should be uncovered across the centre for about one-third of their length. When the shape is approaching a square, it is better to uncover in the form of a cross, the points extending towards but not up to the corners of the plate, this method being termed " crossing." If the surface area of a casting is small, and the drag box does not contain more sand than the cope, turning the box on edge immediately after casting allows heat to be radiated from both sides, and may suffice to correct minor cases of warping. Thicker plate castings are less likely to warp, unless they are very long compared with their width, when the pattern should be cambered, the ends being bent slightly upwards. Warping can often be prevented, however, by partially uncovering the under-side as soon as possible after casting. In a somewhat different category are those castings which have considerably greater mass on one side than on the other. Although, when both are cast from the same metal, a thin casting contracts more than a thick one, the position is apparently reversed when one side of a casting is thin and the other thick. In the odd-sided frame casting shown in Fig 92 (*a*), if the thin side contracted more in cooling, it would be finally in tension. If broken at A after cooling, a gap would open up at the fracture. Instead,

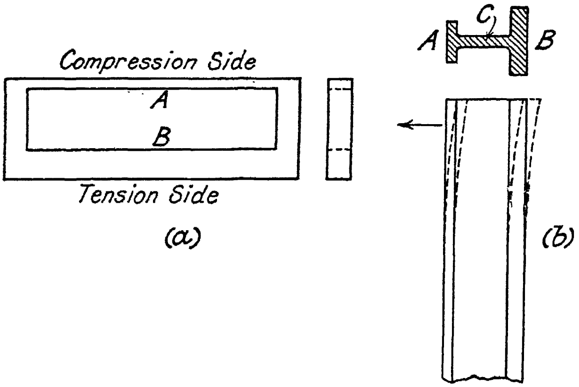


FIG. 92.—(*a*) CONDITION OF ODD-SIDED FRAME CASTING, AFTER COOLING; (*b*) WARPING IN CASTING OF GIRDER SECTION

it will be found that the two ends tend to overlap. If broken through at B, a gap will be found to develop, because the thin side can now expand, pushing the broken ends of the thicker side apart. If these were separate castings, the thinner would show more contraction, and it should be useful to consider why the same result is apparently not obtained when the two form parts of one casting. On cooling, the thin side can solidify and contract to some extent, without hindrance from the thick side, which is still plastic. When the thick side endeavours to contract in its turn, to a lesser degree than with the other, the contraction is opposed by the rigidity of the side which has solidified previously, and is now relatively cool. The thick side, in its efforts to contract, might naturally cause the thin side to bend upwards, but it will tend in any case to be shorter than the thin side. The lesser contraction of the thin side is thus only apparent, the shape of the casting being responsible for the seeming phenomenon.

A similar effect is found in a casting of less peculiar type, that of girder section shown in Fig. 92 (*b*), where, as in the previous example, one side is thin and the other thick. It is convenient to mould this casting with the web horizontal. As before, the side A will cool more quickly than B, and will contract, carrying the still plastic heavy side with it. The latter has to finish contracting after the light side has become comparatively cool, when its rigidity compels the thick side to bend over in the direction of the dotted lines, the heavy side being shorter than the other, for the same reason. To correct this, the pattern is set, during the ramming of the drag-half mould, not perfectly straight, but bent in the direction of the arrow. Bedplates and baseplates, which, as cast, have usually a bottom side heavier than the top one, should be cambered by setting the middle of the pattern below the ends. Then, as the under-side of the casting slowly cools, it pulls down the ends, and a straight casting can be obtained. The camber required depends on the design and length of the casting, varying from $\frac{1}{4}$ in. for castings 6 feet long, to $\frac{3}{4}$ in. or more for castings 15 feet in length. The greater the difference between the masses of the opposing sides, the greater must be the camber.

Annealing for Stress Release. These various effects are found, in greater or lesser degree, in the cooling of all castings of variable section, the thinner portions, which solidify more rapidly, being in compression, and the thicker ones, which solidify later, in tension. The stresses thus set up can be reduced to negligible dimensions, however, by annealing within the temperature range of plastic deformation of the material. For this purpose, Bauer and Sipp* recommend annealing for 2 hours between 500 and 550° C., temperatures at which no appreciable decomposition of the pearlite occurs, so that there is no decrease in the fundamental strength of the material. The removal of stress will naturally often increase the actual strength of the part in question, for the stresses set up in cooling may often reduce the real strength to a very low figure. The use, in annealing, of temperatures which are unnecessarily high may lead to pearlite decomposition and reduction in strength of the iron.

Design. This factor is responsible for many difficulties in the production of good castings. The consequential defects may be divided into two classes—those which develop before solidification is complete, causing drawn and spongy castings ; and those set up during solid contraction, causing castings which are distorted or cracked. The designer can assist in reducing shrinkage defects, by avoiding as far as possible the juxtaposition of heavy and light masses, and by making the change from one to the other gradual instead of sudden. The moulder can often help in this respect, an example being in the filleting of the mould, when heavy flanges join on to the body of a casting. Fig. 93 (*a*) shows a method of making this change a gradual one, and (*b*), a method often found, but incorrect. Any brackets or ribs which adjoin heavier portions are stronger when the fillet runs for some little distance down the light section, as shown in Fig. 93 (*c*). It is useful to have holes cored through the corners of ribs and brackets where these join on to the casting, as in Fig. 93 (*d*), and there is often no difficulty in doing this. It is particularly useful on high pressure work, and should always be carried out when no weakening of the structure is produced. Cracked castings are generally due to variations in rate of cooling, one part remaining hot while another has become comparatively cool. An example is the fractured door casting in Fig. 94, where the very thin centre web cools first, its rigidity resisting the later contraction of the thick outside rim, so that severe stresses are set up. The reduction in strength due to the drilling of the stud holes was then sufficient to cause fracture of the casting. How badly it was stressed before fracture is shown by the width of the crack developed.

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* O. Bauer and K. Sipp, " Casting Stresses and the Means for Avoiding Them," *Die Giesserei*, 1936, Vol. 23, May 22nd, pp. 253-256.

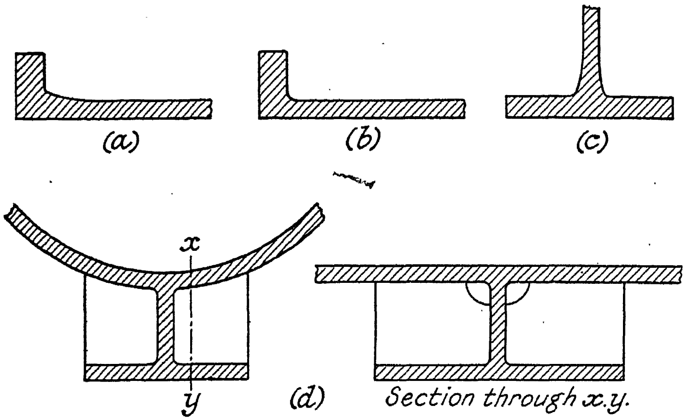


Fig. 93.—(a) Correct Method of Filleting; (b) Incorrect Method of Filleting; (c) Further Example of Filleting; (d) Method of Coring Out, to prevent Leaks

Fig. 95 is an improved design, where later contraction of the rim only pushes up the dome, relieving the stress. The advantage of modifying design to reduce contraction stresses is shown in Fig. 96, of core-boxes forming the back side of a special cover. These are different sizes, but this does not affect the argument. The left side shows the original design which was unsatisfactory, the ribs cracking where they joined the heavy centre boss. The construction is necessarily sturdy, for the centre of the cover carries a ball-race housing, while the casting must be lifted occasionally, with a heavy load hanging from it. The weight having to be kept down to a minimum, thickening up of the ribs was not permitted.

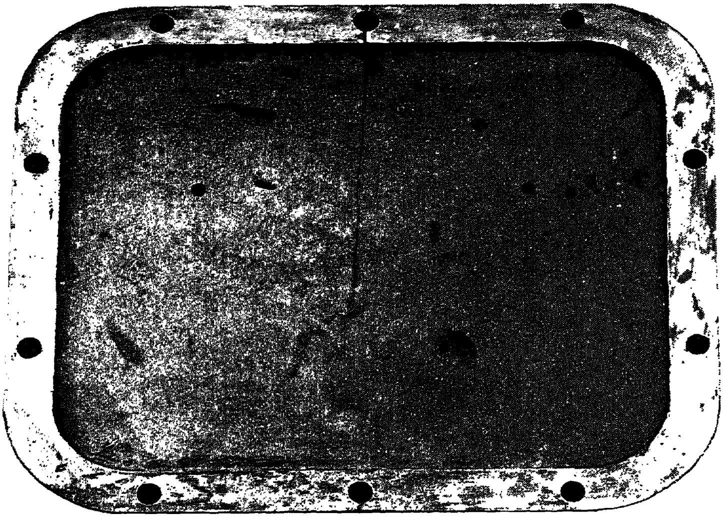


FIG. 94.—FRACTURED DOOR CASTING

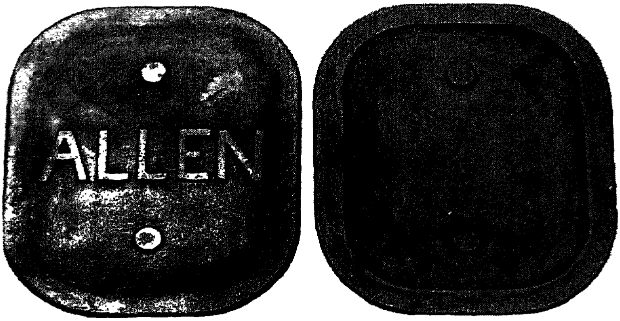


FIG. 95.—IMPROVED DESIGN OF DOOR CASTING

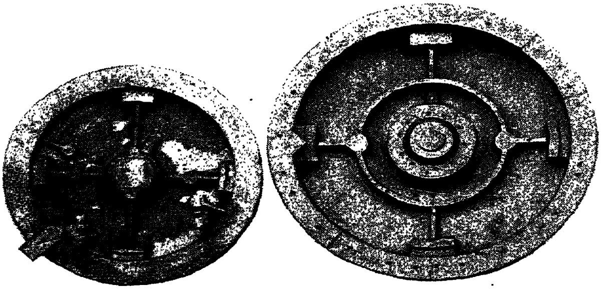


FIG. 96.—OLD AND IMPROVED DESIGN OF COVER

[*To face p.* 152

The problem was readily solved by the modification shown in the core-box on the right, where the ribs, being detached from the boss, are not stressed when this cools later. The curved arms of belt pulleys, hand wheels, wheels for wringing machines and the like, are designed to minimise such stresses, because, when the heavy boss cools and contracts, some time later than the rest of the casting, the curvature of the arms allows them to be sprung slightly without breaking. With small and medium-sized castings, whose design, because of the varying mass effects, renders them liable to crack on cooling, the danger can generally be lessened, and sometimes removed, by stripping the sand from the heavy section, as soon as the metal has solidified. When making some types of pulley castings, the centre core is taken out, and the ends of the boss uncovered, as soon as possible after casting, so that heat is radiated rapidly from this portion of the casting.

Holding Down. When a mould is filled, the hydrostatic pressure of the fluid metal is exerted in all directions, and, unless the cope is fixed firmly, it may be lifted off the drag. With complete box parts, bolted or clamped together, there should be no danger of this, but, if the boxes have no bars, one may have to weight the cope, to prevent the sand from being pushed through it, or, alternatively, to prevent the lifting of both cope and drag, the sand and metal going through the bottom of the box. Where moulds are made in the floor, the normal methods of clamping or bolting the cope to the drag cannot be employed, when weights are loaded on to counterbalance the pressure in question, this process being termed " weighting down." With small work, it is seldom necessary to calculate the lifting force exerted. An experienced moulder can judge the approximate weight required, from the top surface area of the mould. It is better to err on the generous side, for a cope does occasionally lift, to let the metal run out. To prevent this, but also to economise in weighting, the lifting stress can be calculated. This is proportional to the head and density of the molten metal. If A is the area of the lifting face of the cope in sq. in ; H, the height of head from the lifting face to top of runner bush, in in.; W, the weight in lb. of a cubic inch of cast iron and P, the lifting pressure in lb. on the cope, then

$$P = A \times H \times W$$

The lifting force for a rectangular plate, 10 in. wide by 30 in. long, where the distance from the under-side of the cope to the top of the runner bush is 20 in., would be 10 × 30 × 20 × 0·26 lb., or 1560 lb., nearly 14 cwt. The figure of 0·26 lb. per cu. in. is an average figure for solid cast iron, and would be about 0·24 lb. for molten iron, thus keeping on the safe side. The momentum of the metal entering the mould must also be allowed for, where jobs are run quickly. The weight of the rammed cope will usually take care of this. The disposition of the weight on the cope is important. For example, a half-circular plate made in a square box should have the weights put on that half of the cope which covers the casting, or considerably more weight will be required. A little more weight is required on the runner side of the cope, because of the pressure in the horizontal gates.

When bedding, in the floor, large work with a good deal of lifting face, the cope should not be held down by weights. The stocking of large quantities of suitable weights locks up a good deal of metal. The crane will be occupied for a long time in loading and unloading them, when it might have been more profitably employed otherwise. Finally, weighting requires more care in ramming up the cope, to keep the lifters clear of places where one is going to put packing pieces to carry the weights. Copes on large moulds bedded in the floor should be bolted down, as follows. Two or three flat grids, of the type shown in Fig. 97 (*a*), cast in open-sand, about 2½ in. thick, are laid side by side in the floor below the bottom of the pattern. Mild steel hooks, about 2½ in. in diameter, as shown in Fig. 97 (*b*), fit over the lugs, L, and are packed up tightly. These hooks should be of such length as to bring their upper ends just below the level of the foundry floor. Cast iron packing pieces are built up on the grid plates at P, to form a distance piece to the cope, to prevent it from being forced down too low, causing a crush in the mould. Holding-down bars, shown in Fig. 97 (*c*), are used to span across the cope, and connecting bolts (Fig. 97 (*d*)) fit over the hooks in the floor, and pass through the slots, S. All the bolts should be tightened up a little in turn and finally pulled down very tightly, there being no danger of crushing the mould if the distance pieces are packed properly to the cope. If a smaller top part is used than that for which the pit was designed, the crossbars (Fig. 97 (*c*)) are packed up over the cope from the distance pieces placed at P (Fig. 97 (*a*)), and, after bolting down tightly, packing pieces are wedged in between the crossbars and the cope, to prevent any movement of the latter.

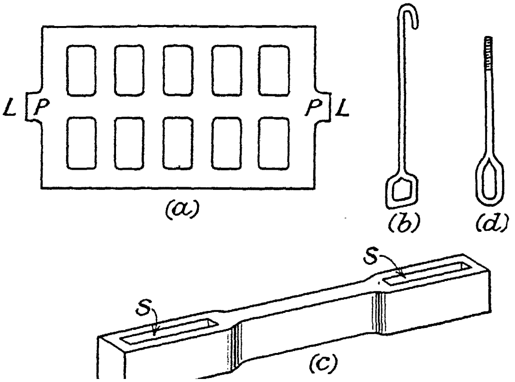


FIG. 97.—(*a*) DIAGRAM OF FLOOR-PIT GRID: (*b*) MILD STEEL FLOOR HOOK; (*c*) HOLDING-DOWN BAR; (*d*) HOLDING-DOWN BOLT

CHAPTER VII

LOAM MOULDING

The facing material used in loam moulding is composed of ingredients similar to those used in dry-sand facing. Such mixtures when milled with an excess of moisture become, however, very soft and plastic, being then termed " loam." This plasticity facilitates the sweeping-out of the mould shape by the aid of strickle boards, supported on suitable tackle, so that they can be rotated at will, as is the general practice when making circular work. The mould walls that carry the facing loam are built up with cheap soft builder's bricks, which are set in position with what is known as " building loam," a material milled wet in the same manner, but composed chiefly of floor sand. Where necessary, the bricks are reinforced with open-sand plates and grids, to supply the requisite stability, the necessary venting being effected by using runs of small cinders, and occasionally, straw, between the bricks, as will be described later. Bricks which are soft and porous give better results than hard ones, because they are not only more readily cut to the shape desired, but they absorb the moisture from the loam more quickly, being thus more efficacious in preventing any sagging and distortion of the mould face. Loam moulding is not confined, however, to circular work that can be shaped by strickles. It is often necessary, indeed, to use a part pattern, where the mould shape deviates from the circular. Skeleton patterns, or even full patterns, may also be used, but loam moulding from full patterns is seldom an economical proposition, and the method would be used only in cases either where the pattern is too large for the moulding box tackle available, or where the size and shape of the pattern are such as to render it very difficult to make in sand. When suitable drying stoves are available, the moulds are transferred to these for drying. They may be dried in position, however, in those cases where the weight of the mould is above the lifting capacity of the crane, or where the mould is too large for the stove.

Appliances for carrying Strickle Boards. In the usual arrangement, the strickle board is attached to a vertical spindle and revolves in a centre bearing, a small example having a portable centre being shown in Fig. 98 (*a*). The spindle is made of mild steel bar, 2 in. in diameter, turned at one end to a suitable taper, which forms the bearing; while the centre is of cast iron, made in an open-sand mould, when the boss may either be cast solid and bored to suit the taper on the spindle; or the hole can be cast in, by using the spindle as a core, in the following manner. A piece of pattern, to form the boss, is bedded into the sand, so as to stand about 1¼ in. above the bed. The three legs are now formed by laying on the bed, against the boss, a flat piece of wood, about 1¼″ × 4″ × 24″, in the three positions in turn, making up the sand round it. Cores are laid on, to form the slots, and the tapered end of the spindle is coated with oil and plumbago, and propped up perpendicularly in the boss, so that the small end just penetrates into the sand at the bottom of the box; while, to facilitate the removal of the spindle, the taper should extend upwards to just above the top surface of the mould. The mould is now ready for casting. As soon as the metal has solidified, a cast iron arm, shown in Fig. 45, is attached to the spindle, when the latter is given a slight turn, and lifted out of the casting.

Portable centres are not desirable for deep moulds, or for those of large diameter, because the weight of the strickle board may cause the spindle to bend. They can be used for quite large work, however, if suitable precautions are taken. Thus the board may be counterbalanced on the opposite side of the spindle; or the distortion of the spindle may be allowed for, by reducing the length of the board slightly, and making the angle between the top edge of the strickle and the spindle a little less than 90°. The board must also be rotated carefully, for it requires only slight pressure to spring an overloaded spindle. When making large loam moulds, the spindle should not be less than 2½in. in diameter, and should be so supported at the upper end as to lead to a minimum amount of distortion, a simple arrangement,

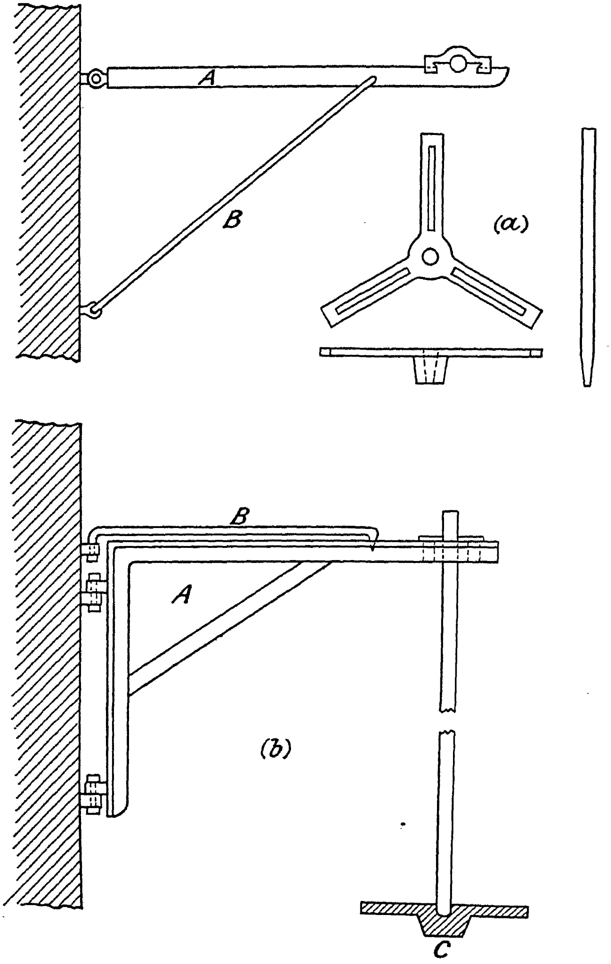


Fig. 98.—(*a*) Portable Centre and Spindle; (*b*) Spindle and Fixed Centre for Large Work

permitting a very quick setting of the spindle in the vertical position, being shown in Fig. 98 (*b*). The swing bracket, A, is made of cast iron or mild steel angles. A tie rod, B, hinged at the wall-end, is made tapered at the opposite end, and this drops into a hole drilled in the top flange of the bracket, thus ensuring that the bracket can be set readily in the position desired. When cast iron is used, the half bearing is made an integral portion of the bracket, but when using mild steel must be bolted on. By making the cap dovetailed as shown, and having an overhanging top flange, it will drop into position without requiring bolting. After the bracket has been set up, the lower bearing is fixed level with the floor, in concrete, and directly under the upper bearing. When loam moulding is being carried on, it is very desirable to have a permanent concrete floor, which need not be more than 3 or 4 in. in thickness, for this permits the rapid setting of portable spindle centres, and also a speedy adjustment of plates round the spindles. There should also be available several sets of stands, strong short ones, for carrying the bottom plates of large moulds, and lighter ones, for carrying shallow moulds. The second variety should be long enough to avoid the need for undue stooping, when striking up the moulds.

Strickle Boards, Arms and Size-Sticks. For ease of working, the strickle boards are profiled on one edge, as shown in Fig. 99 (*a*), the width of this striking edge being not more than $\frac{3}{8}$ in. and the angle of the bevel about 45°. The boards used to strike centre cores theoretically require less bevel than those used to strike outside diameters, because working on the outside of the core gives a wider angle to the bevel. Conversely, when striking outside walls, the angle between the bevelled edge and the mould is reduced, and unless it is cut away well it becomes very difficult to clean out the loam that accumulates in the angle. Except for the application of the finishing coat of loam, strickle boards are rotated with the square edge leading. The side on which the profile is cut becomes therefore very important, as it largely determines which hand the moulder must use for carrying out the various operations. Where, as in some districts, the mode of revolution is clockwise, it is probably inadvisable to attempt to change it, because some moulders get so used to working in a particular direction that they are very awkward when the rotation is reversed. Apart from this consideration, the logical direction is counter-clockwise (*i.e.*, when the board is in position and viewed from the outside, the profiling should be on the left-hand side), because one then moves the board with the left hand, and sets the bricks in position, and applies the roughing loam, with the right. The board is attached to the spindle by means of the arm or spider shown in Fig. 45. This is off-set, so that the sharp edge of the board can be set square with the centre of the spindle, the arrangement being illustrated in Fig. 99 (*a*).

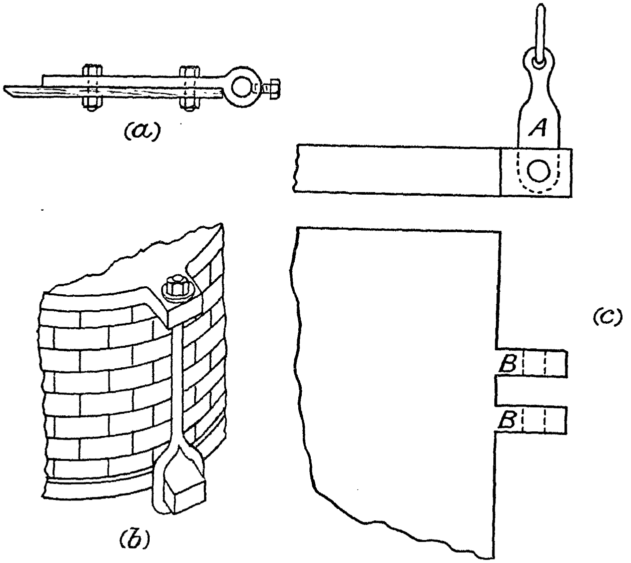


Fig. 99.—(*a*) Method of attaching Strickle Board; (*b*) Arrangement for bolting down Loam Moulds; (*c*) Heavy Top-plate Lug, and Turn-over Shackle

A size-stick or gauge-stick should be applied for setting the board to the correct diameter. The half-hole in the centre is made to fit closely round the spindle, and the ends correspond to the outside diameter to be struck by the board. The same stick, if it is correctly marked out to the required sizes, can also be used for setting the core and top boards. Deep boards are much easier to fix in their correct position than shallow ones, because the size-stick can be used both at the top and the bottom, when a perfectly accurate setting is obtained. With shallow boards, only one setting point is available, and the top edge of any loam board should therefore be made square, so that, by using a set-square between the upper edge and the spindle, in conjunction with the size-stick, the approximate position can readily be found. It is not wise, however, to depend entirely upon this setting of the board at right angles to the spindle, and in the case of flat surfaces it is advisable to try a straight-edge on the face of the mould, before the final coat of loam is put on, when any error can be speedily corrected. If the work is not flat, the setting can usually be checked by putting a straight-edge across the joint before finishing off, and then measuring from this down to some flat surface.

Cast Iron Plates. Nearly all loam moulds are built up on a bottom plate of cast iron, which must be of such thickness that it will not bend when the mould is carried to the stove on it, and that it will resist without distortion the stresses set up in casting. When the mould has a very large surface area, strong cast iron bars can be placed under the bottom plate and over the top plate, being then bolted together to prevent any bending of the plates during casting ; otherwise, the straining apart of the plates in the middle may cause the casting to be thicker at this place than it should be. For shallow work, 2 to 2½ in. is a suitable thickness for bottom plates up to about 6 or 7 feet in diameter. The thickness must be slightly increased for plates of larger diameter and as the load on the plate usually increases with the depth of the job, so must the thickness increase, until it may reach a maximum of about 5 in. in thickness for a large deep mould. The top or cover-plate is usually similar in shape to the bottom one and is generally covered on one side with short dabbers, to carry the loam. This plate is rarely subjected to so heavy a load as a bottom one, a plate for a mould having a flat upper surface only carrying, indeed, about 2 in. of loam on its under-side, which forms the face of the mould. Top plates can therefore be made a little thinner than bottom ones, but one must calculate for casting stresses, as well as mould weights, when deciding the thickness of a plate. The same factors must also be taken into consideration when making plates which are rectangular or of other shapes. All bottom and top plates must be provided with suitable lugs at intervals round their outside edges, so that they can be lifted about as required, and also for bolting together for casting, as shown in Fig. 99 (*b*). It will be seen that the lug on the top plate has a hole cast in it, through which the bolt passes. Four such lugs would be sufficient for bolting down plates up to six feet in diameter, but large plates will require six or even eight lugs. If the lugs on large work are too distant from each other, there may be slight straining between them, when, if the plates are too weak, a run-out may occur. Also, if the lifting pressure is high, it may not be advisable to depend on four bolts, as foundry tackle seldom remains in perfect condition for a long period. On large top plates, it may be necessary to cast, on one edge, a specially strong lug, having a hole large enough to take a suitably strong chain for turning-over purposes. Fig. 99 (*c*) shows a design of double lug which can be cast on to thick plates, and is very suitable for turning over heavy weights without damaging the lifting chains. A special mild steel shackle, A, is made to fit between the halves of the double lug, B B, a mild steel pin, about $1\frac{5}{8}$ in. diameter, being passed through the holes. Building or binder plates are used when necessary at intervals between the main plates, to support the brickwork, the number employed on any job depending on the shape and depth of the casting. All plates are made on an open-sand bed, and have holes and staples cast in as required, while they may also carry wrought irons, or cast dabbers, to support the loam and brickwork. Any plates such as top plates, joint plates or others near to the casting which are required to carry loam on their surfaces must have the burnt sand, which adheres to them from the open-sand bed, scraped and brushed off, after which they must be claywashed before being used, to help the adhesion of the loam.

Building. When building up the bricks, it is only necessary to use reasonable care, for they do not come into contact with the metal, but only support the loam which forms the actual face. The bricks are placed on a layer of building loam, $\frac{1}{2}$ in. thick, with a distance of about $\frac{1}{2}$ to $\frac{3}{4}$ in. between them, this space, in the case of the side walls of a mould, being also filled in with soft building loam. Loam must always be applied by means of the hands and not with a trowel. The first method is much faster, and more convenient from all standpoints. Any brickwork that is used to form the under-side of a mould, over which metal flows when the mould is filled, must be vented, to prevent the face from scabbing. This may readily be accomplished by ramming small cinders with a file into the spaces between the bricks, leading the vent away to the outside, this arrangement being illustrated in Fig. 100 (*a*). It will be seen that whole bricks are used round the outside, the intervening spaces being filled with loam; while old half-bricks are employed in the middle, with small cinders round them, leading to the vent pipe. When building shallow moulds, where the bottom face consists of a single row of half-bricks, as in the last figure, those in the middle can be laid on about ½ in. of dry floor sand, and, if cinders are not available, the spaces between can be satisfactorily vented by filling in with dry floor sand, which, as in the case of the cinders, is kept about ½ in. below the top faces of the bricks, the vent being led away through pipes. The thickness of the side walls round the mould depends to some extent upon its shape, because, where the higher parts overhang the lower ones, the lower brickwork must naturally be made wide enough to support that above it. When dealing with plain walls, it is seldom necessary to build a wall more than 9 in. thick, and a 4½-in. wall is usually sufficient for shallow moulds. The inside walls of deep circular moulds, such as large pipes and cylinders, may, except for a few courses of 9-in. brickwork at the bottom, be also made 4½ in. thick, for the inner ring of brickwork is in compression, and its shape thus prevents the metal from bursting it inwards. The outside brickwork on all loam moulds having a depth greater than 8 in. must always be supported, or the lateral pressure of the metal may lead to collapse, the means of preventing this being discussed later. Where the shape of the mould is such that a large mass of bricks must be used, it is advisable to employ cinders, not only in the spaces between the inner bricks, but also for bedding the bricks on, so that the interior bricks are completely surrounded by cinders.

This not only secures better venting, but also accelerates the drying of the mould considerably. Straw is also used for venting, being trailed in between the bricks and loam from small awkward pockets at the mould face back to the cinders, or right through to the outside of the walls. During the drying of the mould, the straw shrinks a good deal, or may sometimes be burnt out more or less completely, so as to leave small vent passages by which the gas can escape from the mould face.

When any part of a casting projects into the brickwork, special precautions must be taken to ensure that this is compressible to some extent, or the solid contraction of the metal may lead to cracked or broken castings. The same remarks also apply to the internal mould walls of hollow castings. In the first instance, where the distance between the projecting points is small, not more than about 2 or 3 ft., for example, and providing that the casting is not too thin, the cinders and loam between the hard bricks will allow sufficient contraction to take place. When, however, this distance becomes great, or even with short distances on castings which are very thin, it is necessary to replace a

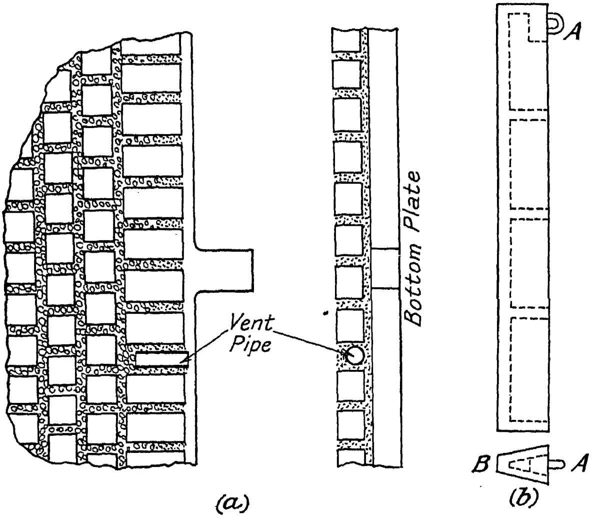


Fig. 100.—(*a*) Venting of Loam Mould; (*b*) Design of Easing Bar

certain proportion of the hard bricks by loam bricks, the extent of replacement naturally depending upon the amount of contraction that must be allowed for. Loam bricks are made of soft building loam in an open-frame box, having the same internal dimensions as in the case of the ordinary hard bricks, *i.e.*, 9 in. by 4½ in. by 3 in. When in use, the box is kept wet by frequent immersions in a bucket of water, so as to prevent the loam from sticking. It is quite common practice, both to make and to dry these on the floor of the stove. As an illustration of the use of loam bricks for this purpose, we may take the case of cylinders, condensers, large pipes and similar castings, which are cast on end. These have usually an external flange cast round each end, and since the bottom flange must be covered with hard bricks, or grids, so as to prevent any falling-away of the overhanging portions of the mould, it becomes necessary to make provision for the contraction to take place in a downward direction. With castings not greater than about 7 feet in length, it will be sufficient if one row of loam bricks is placed under the top flange, and there is a reasonable quantity of building loam between each layer of hard bricks; for the amount of contraction vertically is usually less than that in a horizontal direction. With castings over 7 feet long, two rows of loam bricks can be used. That portion of the mould which forms the inside shape of such castings is always compressed by the contraction of the metal, and where the area is great, or the metal is thin, or both, it is necessary to guard against fracture of the castings during cooling. Here there are so many variable factors that no hard and fast rules can be laid down. The thickness of the metal walls, the hardness and strength of the metal, the cross-sectional area of the core, and the numbers and sizes of holes that are cast in the vertical walls, all play some part in deciding the matter, and, while it is naturally always advisable, especially on work of a non-repetition character, to use a considerable margin on the side of safety, the following suggestions should form a useful guide. In the case of diameters up to about 3 feet, with a metal thickness, round the core, of about 1 in., and if one uses only a 4½-in. wall, built with half-bricks, leaving spaces, for the building loam, of at least ½ in. between them, then no further precautions should be necessary. Care should, however, be taken to ensure that the space between the bricks is preserved right across the width of the wall. Bricks seldom break square with their ends, and, by laying the greatest length of the half-brick farthest away from the spindle, the tendency for the spaces to be very wide on the outside of the circle is diminished. If it is necessary to build the core with a wall 9 in. thick, and, even with a 4½-in. wall, if the castings are very thin, the danger of fracture is much accentuated. Perhaps the greatest safeguard against this is to remove a vertical "slice" of the mould wall very soon after the metal has solidified. In the case of moulds for cylindrical castings having open ends, this can be accomplished simply and economically by building in the brickwork a wedge-shaped cast iron bar, sometimes termed an "easing-bar," as illustrated in Fig. 100 (*b*). It should be cored out from the back, as shown, for lightness, and should have a mild steel staple, A, cast in, near to the end, for lifting purposes. The bar is placed in position, with the thin edge, B, about 1 in. from the mould face, before laying the first row of bricks, and it is of such length as to reach within a few inches of the upper end of the casting. By having the bar short enough to go just under the top building plate, one can use a full ring binder, thus obtaining a much stronger structure. When this procedure is adopted, the cope is lifted off soon after the casting has solidified, the ring binder on top of the core is lifted off, and the easing-bar is withdrawn, so as to leave in the circular brickwork a wedge-shaped gap, permitting ready compression, with a correspondingly small resistance to the contraction of the casting. In practice, shorter bars are often used, with loam bricks built over them, and these can quickly be cut out, using a chisel-pointed bar, after casting, before removing the cast iron bar. When dealing with very large diameters, two or three easing-bars may be used, and for large castings of rectangular section it becomes necessary to have one in the middle of each of the four walls, so as to break the resistance to the contraction of each side of the casting. In many instances, vertical columns of loam-bricks can be used instead of easing-bars, but, besides being more costly, the core is not nearly so readily compressed. There are many large hollow castings, whose design does not permit of the use of easing-bars, in which case it may be necessary to construct the core almost completely of loam-bricks. Even when this procedure is adopted, the design may be such as to necessitate the removal, or partial removal, of the core after casting. The production of such a casting is described later. It may be remarked that, besides being useful in facilitating contraction, loam-bricks constitute a very useful medium for absorbing the moisture from the wet mould, thus accelerating drying, in which respect they are very much better than ordinary building bricks. They are extensively used for this purpose between the dabbers on top plates, and are much more readily cut up by a half-round file into suitable shapes for such purposes, than the hard bricks are.

Preventing Lateral Strain. All loam moulds but those of only two or three brick courses high, require some means of support other than the brickwork, to prevent them bursting out sideways during casting. When the depth is only a little more than the limit mentioned, circular moulds can be held together by putting a chain round the middle of the brickwork, and tightening up by lightly driving in a few wooden wedges. In the case of deeper moulds, unless some special means are provided during the building of the mould, for coping with lateral strain, the necessary resistance is generally supplied either by sinking them in a pit, or encircling them with a cast iron frame, afterwards ramming sand hard all round the brickwork. The strain on very deep loam moulds is enormous, and they must therefore be rammed very hard indeed. Pneumatic rammers are excellent tools for this purpose, for long periods of ramming by hand are very fatiguing. A depth of about 10 in. is safe and suitable for each individual ram. The strain in casting naturally decreases towards the top of the mould, and the ramming need not be quite so hard. A common method of avoiding the necessity for ramming round the moulds is to use cast iron dabbers attached to the outside of the bottom or building plates, against which the bricks are built, and a job in course of construction which employs this method is seen in Fig. 107.

In the case of a deep mould, several of these plates might be used, one above the other. Near to the bottom of a deep mould, the dabbers should not be too long, because of the very great strain to which they are subjected, and even near to the top of the mould it is not advisable to have them more than about 18 or 20 in. long, because all the material has to be lifted over the top of the dabbers, and building thus becomes more difficult and expensive. In another method, which finds a limited application on moulds of medium depth, the bottom plate is cast with a projecting ledge running round the outside, while the top plate has slot holes cast in, at close intervals round the periphery. When building up the mould, the bricks are kept about one inch back from the ledge, and, after closing, cast iron bars are dropped through the slots in the top plate, so as to rest against the ledge on the bottom plate. Soft loam is then pushed into the small spaces between the bars and the brickwork, preferably while the mould is still warm, so that the loam hardens quickly. Another method commonly used in some districts takes advantage of the fact that very great pressure is required to displace a single row of bricks, without disturbing the rows immediately above and underneath the row in question. In this case, after every two courses of bricks have been laid round the outside of the mould, a light circular cast iron plate is bedded on soft building loam on the brickwork. Thus, every row of bricks has a plate, either over or under it. Although this method necessitates the putting of a considerable amount of cast iron into stock, it is possible, if the necessary lifting facilities are always available when required, to complete the building more rapidly than by those other methods designed to avoid ramming round the moulds. When the brickwork is supported on the outside, one has to build to two faces, the strickle board on the inside, and the cast iron dabbers on the outside. On the other hand, by using building plates, as described, the bricks can be laid to the strickle, and the outside can be left to some extent to look after itself, although the outside of a loam mould built by an expert moulder is of course always trim and neat. If the mould is circular, or of such other shape that a number of similar plates can be used in building up, it is possible to cast several plates in one open-sand mould, providing that the sand is made up round the sides to a depth of about 3 in. After pouring the first plate, parting sand is sprinkled thickly over it, and, after the plate has cooled down at least to a dull-red heat, a second one can be poured on the first, the operation being repeated two or three times. This method is generally used on medium-sized plates having a comparatively light section. When an upper support is used, then, by casting, in the plates, a slot about 3 in. wide, they can be placed in position without disturbing the spindle, it being naturally necessary to clamp or bolt the loose ends together across the slot.

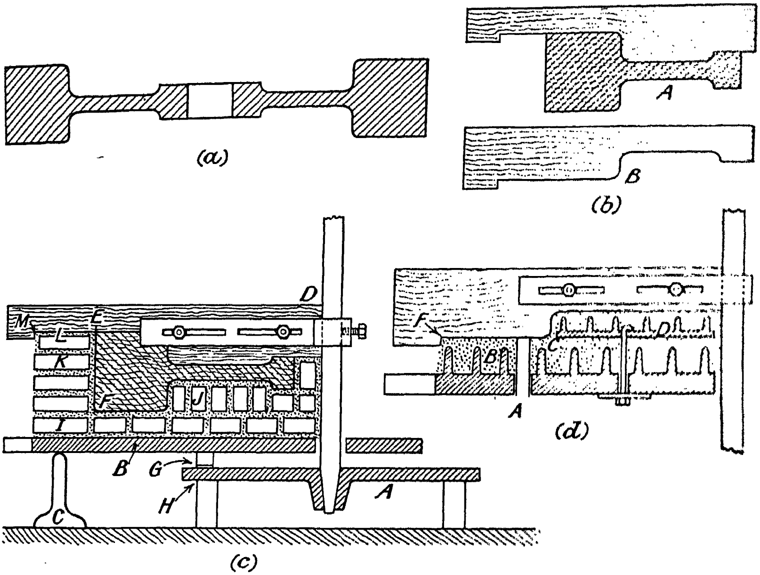


Fig. 101.—(*a*) Section through Flywheel Casting; (*b*) Strickle Boards used for Flywheel; (*c*) Half Section of Bottom Half Mould for Flywheel; (*d*) Half Section of Top Half Mould for Flywheel

Method of Making a Simple Loam Mould. The main principles of loam moulding may be illustrated in the case of the flywheel casting, shown in section in Fig. 101 (*a*). The two strickle boards required are seen in Fig. 101 (*b*). The bottom board, A, is used to sweep up the bottom half of the mould, and, when the shape permits, it is usual to mark out on it a half-section of the casting, for reference. B is the top board, used for sweeping the cope. In beginning operations, the three-legged centre, A, in Fig. 101 (*c*), is placed on three stands, and, after cleaning the bearing and spindle, a little tallow or thick grease is wiped on to the latter, which is then set on the centre bearing, as shown. The circular bottom plate B is put over the spindle and set on three taller stands, C. The next operation is to fix the arm on the spindle, and to bolt the bottom board to it, taking care to set the angle with a set-square, and to check the diameter by using the size-stick at the points E and F. Provided that the stands carrying the centre and bottom plate have been stood on level ground, the board should now swing round approximately parallel with the plate, in which case the packing pieces, G, are wedged in position, to prevent the spindle centre from moving. If the floor is uneven, however, the distance between the board and the plate should be measured in three positions, over each leg of the centre. Where the distance is small, the board is gently lifted, this also causing the leg of the centre to lift, and wedges are then put under it at H. When the board has thus been made to run parallel with the plate, the centre is tightly wedged up at G, as before. The arm carrying the board is now raised or lowered, as required, to allow space for one row of bricks under the rim of the wheel. This completes the setting of the tackle, and building can now be begun. A row of whole bricks, I, is now set on building loam, with their ends standing $\frac{7}{8}$ in. back from the edge of the strickle, all round the outside of the plate. Half-bricks, spaced about $\frac{3}{4}$ in. apart, are laid on building loam all over the bottom of the plate, small cinders being rammed, with a file, into the spaces between them, leading away to the outside through small pipes, as in Fig. 100 (*a*). Either hard bricks or loam bricks may be cut to fill in the cod at J, while a 9-in. wall is built up round the outside at K. For a light shallow casting, a 4½-in. wall will be sufficient. Soft facing loam is next rubbed well on to the face of the bricks in front of the square edge of the board, and strickled off by degrees until the whole mould face, and the joint L, is covered with loam. After standing for a little while, until the bricks have absorbed some of the moisture, so that the loam has become " stiff," the corner near E is made good with fairly stiff loam, which, however, is kept just clear of the board, or it may be dragged off as the board passes over. All loam adhering to the working edges of the board is now cleaned off, and a further coat of loam that has been made quite soft, by mixing with water, is rubbed over the rougher coat that was applied first, and is again struck off, still using the square edge of the board. As in the case of the roughing coat, this second coat is also added a little at a time, the board being worked backwards and forwards, as required. Thin facing loam is now sifted through a $\frac{1}{4}$-in. riddle, either directly on to the face of the mould, or into a bucket, from which it may be splashed by hand on to the mould. After rubbing this thin loam lightly and quickly all over the mould face with the hand, the board, which has again been cleaned off, is given one complete revolution in a reverse direction, *i.e.*, with the profiled edge leading, the surplus loam that accumulates on the rim in front of the board being scooped out with the free hand as the board is rotated. During the application of this final coat, loam must also be fed on to the outside edge of the joint at M, so that a good edge is left for registration purposes. The strickle board and spindle are removed in turn, and the hole left by the spindle is filled up, the bottom half of the mould being now ready for the stove. The top plate is similar in shape and size to the bottom one, and carries short dabbers all over one side of it. For purposes of venting, several small holes are cast in it. There are three holes, each about 3 in. in diameter, for the runners to pass through, at A in Fig. 101 (*d*), and a larger one over the rim on the opposite side for the riser. The dabbers should be long enough to carry at least 3 in. of loam at B, or the uneven heating from the metal, as it cools in the mould, may cause the plate to crack. This plate is placed over the centre, and the top board is set in exactly the same manner as the bottom one. Before beginning to strike up the cope, a little loose straw is scattered all over it, and the dabbers and plate are clay-washed. Pegs for the runner gates can be passed through the three holes at A, and stiff loam filled round them, or, alternatively, the holes may be filled with pieces of loam brick and the gates drilled through after stoving. Very stiff loam can then be pressed over the dabbers to the edge of the board at C, or alternatively, softer loam can be used, in conjunction with pieces of loam brick, which have been dipped into clay-water, and are then pushed into the loam, between the prodders, to absorb the moisture. The grid D, having dabbers to carry the loam in the cod, is next bolted on, as shown, and the grid is filled in with loam, as before, and struck off with the square edge of the board. When the loam has become fairly stiff, a coating of thin loam is first applied and strickled off with the square edge, after which a coat of very soft loam is sifted on, the surplus being removed with the profiled edge of the board, exactly as described for finishing off the drag, the cope being now ready for drying. It will be noted that a sharp edge is formed with the board at F, this diameter coinciding with that struck on the drag at M. After the half moulds have been thoroughly dried, the excess loam, left where the respective strickle boards finally came to rest, is filed away, and the whole of the mould face is dressed over, using a piece of file or rough wood, or wood over which glass paper has been stretched. This dressing removes the glaze, and makes it much easier for the blacking to be applied. The runner and riser gates are then rubbed out to size, all dust is brushed or blown from the face, and a suitable black-wash is applied. If the casting is required to have a good finish, some care is needed in blacking loam moulds. When the mould is hot, the first coat must not be put on too thickly, and all subsequent coats should be applied before the previous one is dry. This necessitates the blacking of large moulds piecemeal, and one must then be careful to keep the surface smooth where the different portions overlap. There is, in such places, a great tendency to thicken up, but this can be prevented by washing over with water, and then sleeking down with the trowel. After the final coat has been put on, each individual portion can be sleeked, or, alternatively, rubbed over with the palm of the hand, the mould being finished off in either case by giving a coat of blacking water, or thin gum water, applied with a fine brush. Loam moulds take the blacking well when they are fairly warm, but they should not exceed the temperature at which the hand can be held comfortably on them.

The mould is returned to the stove for a few hours, to dry the blacking thoroughly, when, as no cores are required, the top half is turned over, and closed on to the drag. The location joint, F, running round the cope, is placed directly over the corresponding one on the drag, the two half moulds being thus set concentric with each other. In some districts, a spigot and socket guide, as shown in Fig. 102, is used for this purpose, and, while this may at first appear to be a more exact method, it has in practice several disadvantages. In the first place, small errors in setting the diameter size of the boards causes the fit down the oblique joint, A, to be either too loose or too tight. Spindles often become slightly distorted, so as to run a little out of truth, and this causes similar difficulties. Also, the locating joint, A, is out of sight, and, although this difficulty can be overcome to some extent by cutting away a portion of the drag joint in four places round the circumference, as shown dotted in the figure, one can only see then by using a lighted taper, while, if the cope should be $\frac{1}{4}$ in. small, it can only be set right with some trouble, by using $\frac{1}{8}$-in. distance pieces at four points round A. Finally, location by means of spigot and socket involves the carrying of extra loam on the top plates. When using external location, however, even if one part is slightly smaller than the other, the difference can very readily be divided, to obtain concentricity.

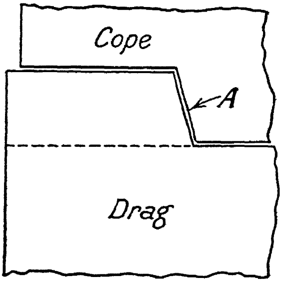


FIG. 102.—SPIGOT AND SOCKET REGISTER

After the mould has been closed, the two halves are bolted together by the lugs on the plates. Loose stirrups may be placed over the bottom lugs, and hook-bolts passed up from these through the holes in the lugs in the top plate. Special stirrup bolts, as shown in Fig. 99 (*b*), are stronger, and, if made from mild steel of 2 in. diameter, will be suitable for a wide range of work. They should be stocked in several lengths, and, by having a supply of straight lengths screwed at both ends, and also supplies of double length coupling nuts, any length can be made up, as desired, while, at the same time, only a minimum quantity of material is kept in stock. The lugs should be set directly over each other, so that the bolts stand vertical. If the top plate is set so that it is twisted round slightly, so that all the bolts are sloping slightly in one direction, the hydrostatic pressure during casting may cause the cope to jump out of its correct position, so that the bolts are now truly vertical, when the registration will be incorrect, and the casting cross-jointed. After bolting down, the mould is lifted on to a sand bed, and either a moulding-box middle part, or a cast iron ring, is placed round the brickwork, so that floor sand can be rammed hard round the outside of the mould, to resist the lateral pressure during casting. If a suitable frame is not available, the mould may be rammed in a pit dug in the foundry floor. The runner and riser bushes are made up and the job is ready for casting. With a loam mould for a massive casting of this type, it is essential to keep the risers tightly sealed until the mould is filled, or the lack of air pressure in the mould will result in what is termed the "drawing-down" of pieces of the curved portion of the cope. The true explanation is that the great heat causes cracking of the mould face, and pieces may actually fall out, if there is not sufficient pressure to keep them up. With the average loam casting, the danger is much less, and it will be sufficient if a piece of paper, with a portion of loam brick resting upon it, is laid over the open riser. Castings of this type have frequently to be machined all over, and, in the case of massive ones, from four tons in weight upwards, better results are obtained by running from the outside. Since, in order to keep up the cope, the mould has to be filled quickly, it is preferable to use a number of separate gates, rather than one or two large ones. When great quantities of metal pass rapidly from the runner bush down one or two gates, there is a tendency for air and dross

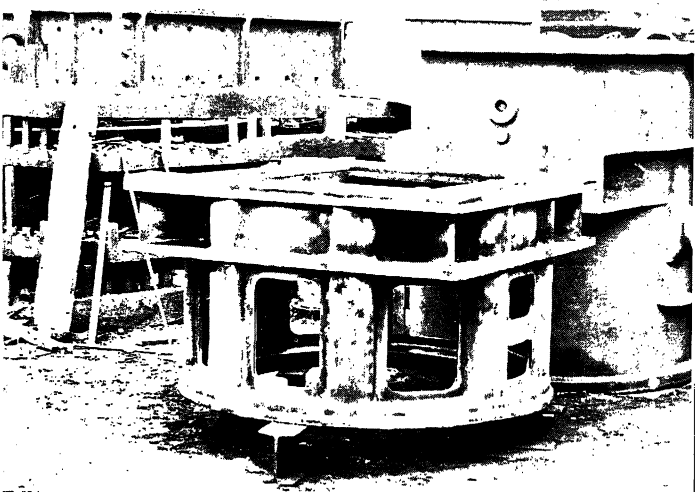


Fig. 103.—Motor Base Casting

To face p. 175]

to be drawn down with the metal, so as to lead to the occurrence of small defects in the casting in the neighbourhood of the runner. A quite usual effect shows characteristic black specks of oxidised iron on the surface, under which is a small hole or holes due to gas reactions. Taking the metal from the runner bush through a number of smaller gates causes much less turbulence, with a considerably diminished risk of obtaining these defects.

Production of a Large Motor Base Casting. Having discussed the principles of loam moulding, and the production of a circular casting of plain type, it is now proposed to describe the method of making a somewhat more complicated casting, involving a minimum amount of expenditure on pattern-making. Fig. 103 is a photograph of the finished casting, standing with the bottom upwards, the position in which it was cast. Fig. 104 shows a half-plan, a part elevation and three half-sections of the same job. These drawings have for simplicity been inverted to the casting position, but it is of course customary to draw them in the actual working position. For a job of this kind, it is necessary to use, in addition to the strickle boards, a number of loose pieces of pattern. By making the bottom of the casting upwards, the top plate, except that it carries two facings, can be flat. The job will be considered, from this point, solely in relation to the position in which it is to be cast. In order that the moulding shall be simplified as far as possible, it is desirable to construct the main centre core permanently in position on the bottom plate, and to lift away the outside of the mould. The first problem that presents itself is that of the double ring running all round the bottom, because leaving the core stationary makes the internal ring inaccessible. In order to overcome the difficulty, a core-box is constructed from which a ring of segment cores are made to the section shown dotted at D in Fig. 104. It will be noted that these segment cores are made to slide into position from the outside after the main core has been dried and blacked. If a set of plates had been made specially for this job, they would have been square on the outside, extending about 10 in. beyond the rectangular flanges that run all round the top of the casting.

In this case, circular plates, being in stock, were used to save expense. The first operation is the placing in position of the bottom plate, and the sweeping of the joint seating on which the outside of the mould has to be constructed. The arrangement is shown diagrammatically in Fig. 105, and a photograph of the finished seating can be seen in Fig. 110.

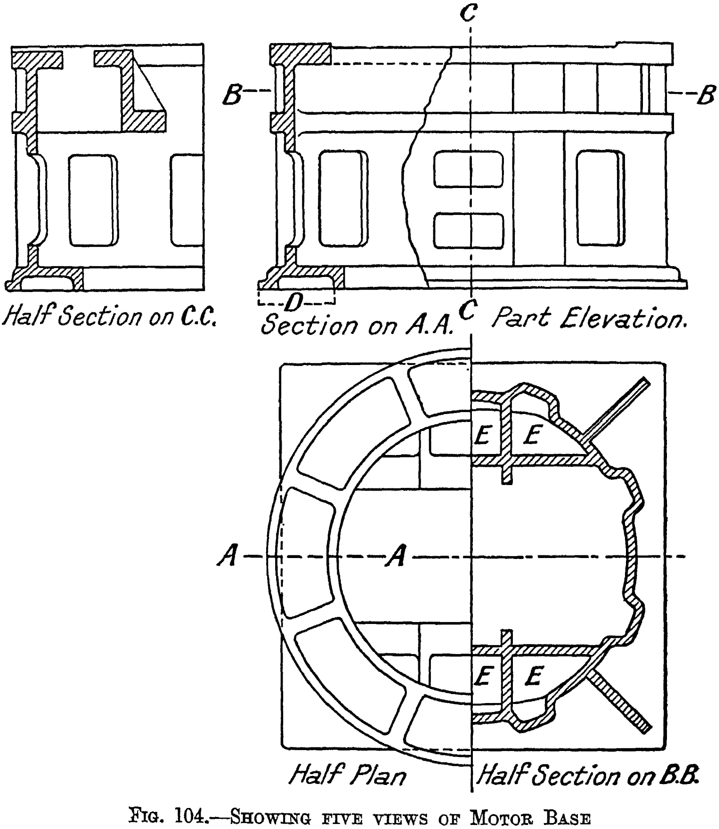


Fig. 104.—Showing five views of Motor Base

Since the internal diameter of the ring plate used to carry the outside is slightly too large, the taper joint of the seating has been extended a little way beyond the edge of the casting; or it must otherwise have sloped directly down from the extreme lower edge, in order to reduce the overhanging portion to a minimum. After the seating has been struck up, the board is removed, and a few small bucket-fires are stood round to dry it partially. The strickle board made to shape the outside wall of the mould is now set in position, and the size checked in two positions with the stick provided for that purpose. The arrangement of the strickle and loose pieces is shown in Fig. 106. Paper to make a parting is stuck with clay-wash on to the oblique joint, and parting sand is sprinkled on the horizontal portions. Two permanent lines should now be marked, opposite each other, down the outside edge of the bottom plate. Their correct position is found by laying across the seating a straight-edge, having a half hole cut out of it for fitting to the spindle, and dropping a plumb-line from the side of the straight-edge running across the centre of the spindle. It is essential that these marks should be set exactly across the centre of the spindle, because the radial positions of all the loose pieces have to be set from this permanent centre line. By cutting the mark lightly into the plate with a chisel, one avoids the possibility of its being accidentally obliterated. The next operation is to clean off and clay-wash the under-side of the ring that carries the outside brickwork, when, after spreading about ¾ in. of soft loam quickly on to the horizontal portion of the joint, the ring is put on and bedded down hard, by knocking it with the end of a heavy bar, until one begins to squeeze out the loam both inside and outside. The surplus on the outside is removed by the hand, and that on the inside wiped up the plate, the small space between the plate and the taper

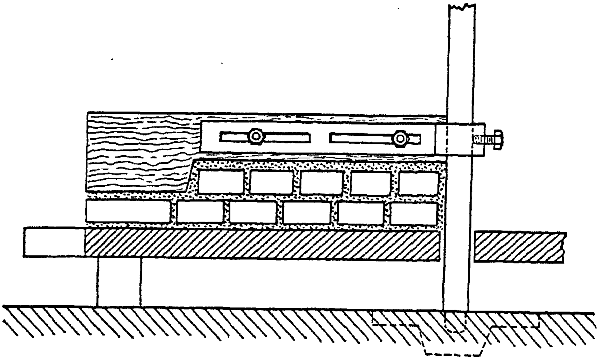


FIG. 105.—METHOD OF SWEEPING SEATING JOINT

seating being filled with stiff loam. A row of wooden segments, cut to form the ring-flange which stands beyond the vertical wall, are then laid all round the base of the strickle board, as shown at A, and the eight pieces of pattern, B, which give the shape of the columns where the wall departs from the circle, are set in position on the wooden flange. Of course the columns must be spaced out correctly in relation to the permanent centre-line. The outside of the mould is now built up to the under-side of the first rectangular flange which stands out on top of the eight columns. A photograph of this portion of the mould in course of construction is seen in Fig. 107. It will be seen that the cast iron lifting-ring

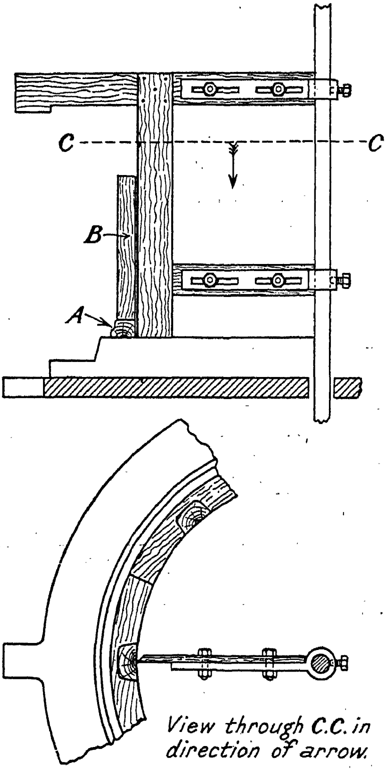
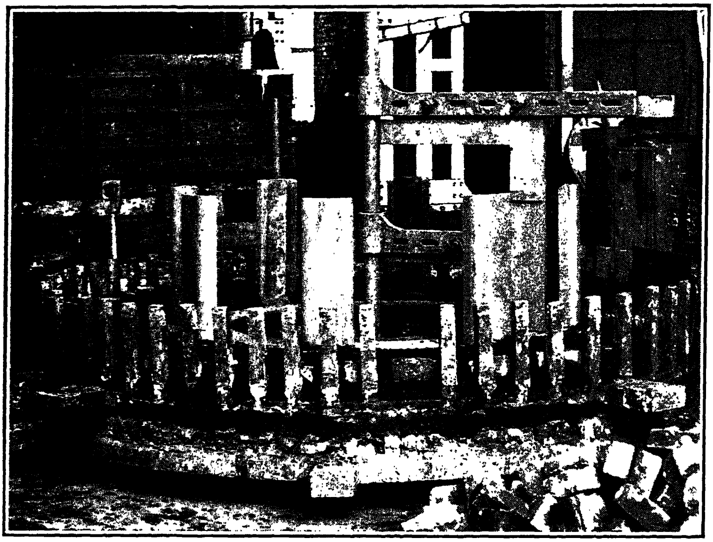


FIG. 106.—ARRANGEMENT OF STRICKLE BOARD AND LOOSE PIECES



G. 107.—Outside Wall of Mould for Motor Base Casting, in course of construction

[*To face p.* 178

plate carries, round the outside, a row of dabbers, to resist the lateral pressure set up in casting. The only special precaution necessary when building this portion of the mould is the laying of a course of loam bricks immediately under where it is intended to form the rectangular flange, and the packing, in the interstices between them, of a few cinders, these being led away to the outside, for the purpose of venting. A piece of board is now screwed to the strickle, to sweep off a level bed, on which are laid the four pieces of timber to form the first square flange. These having been set out, a flat parting joint is made, level with the top edge of the flange. After allowing to stand until the loam is quite firm, parting sand is sprinkled on, and the four diagonal corner ribs and the eight short extension pieces, to continue the columns, are spaced out in their correct positions. A second ring-binder plate—which, excepting that the inside shape is made square and slightly larger than the flanges, is similar to the one on the bottom joint—is next bedded on loam in the same manner as the first. Over the corners of the first square flange are now placed grids which rest on the binder, and carry the structure between the two flanges. The building is now continued up to the top flange, and, after this has been bedded in place, by the same method as used for the first one, loam is strickled on to the face of the mould—as described for making the flywheel casting in loam—and the joint is struck off across the top of it, the outside of the mould being thus completed. The next operation is the making of guides, so that this part of the mould can be correctly located a second time in the same position. The method by which this is accomplished is illustrated diagrammatically in Fig. 108, the loam immediately above and below the joint being trimmed off to match, when small V-shaped notches are cut out at intervals all round the circumference. The strickle board is now removed, but, before the spindle is taken away, the main centre-line is cut across the upper joint register that has been struck all round the mould. This centre-line is necessary, because the top plate carries two long facing pieces and has therefore to be set to a definite radial position, as well as being concentric. The making of the outside of the mould is now complete, and it is lifted off its seating and lowered on to suitable stands near by.

The inside of the mould has now to be constructed. Several small pieces of plate or board are laid directly on the seating, to preserve the guides and joint face, and the making of the main core can be begun. Since this is to be a permanent fixture on the bottom plate, the amount of reinforcement necessary is comparatively small. After setting the strickle board, another row of wooden segments is placed round the inside, these being of such shape as to form the inside face, and that part of the core print which stands inside the circular wall, shown at D in Fig. 104. The arrangement of the board and loose segments is seen in Fig. 109. As the outside shape of the casting is such as to make it difficult to fill the mould from the outside, three runners are placed so that the metal passes through the core and enters the mould opposite to the radial ribs which connect together the two rings at the bottom of the mould. The position of the runner gates is shown in the same figure. After building loam bricks inside the loose pieces, a ring of cast iron grids are bedded on loam over the internal flange, and the core is built up to the level of the brackets and ribs. Since the metal thickness is small, and the general structure of the casting is comparatively weak, the core is constructed almost entirely of loam bricks, those in the centre having, between them, large spaces which are filled in with cinders. A fairly large core grid is now laid in each side of the core, just under the brackets, the prodders of the grids standing

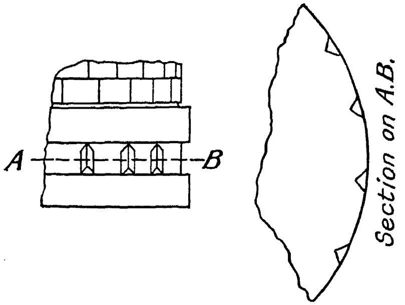


FIG. 108.—GUIDES ON SEATING JOINT OF LOAM MOULD

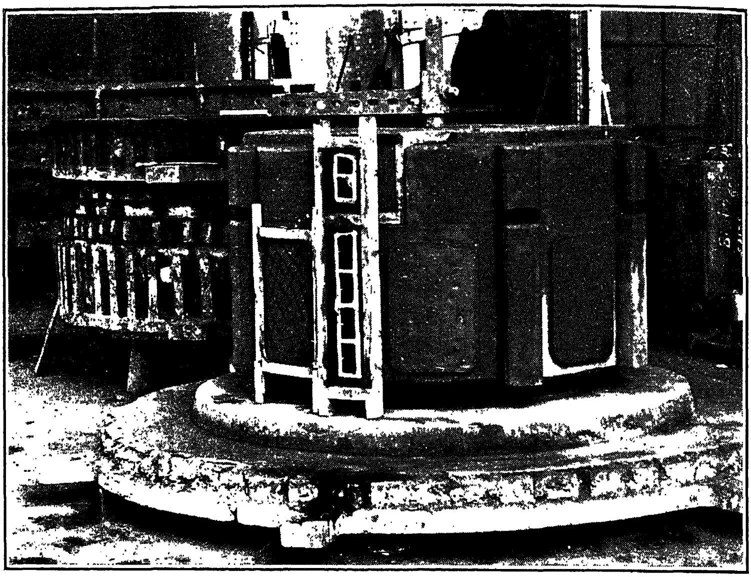


Fig. 110.—Core for Motor Base Casting, nearing completion

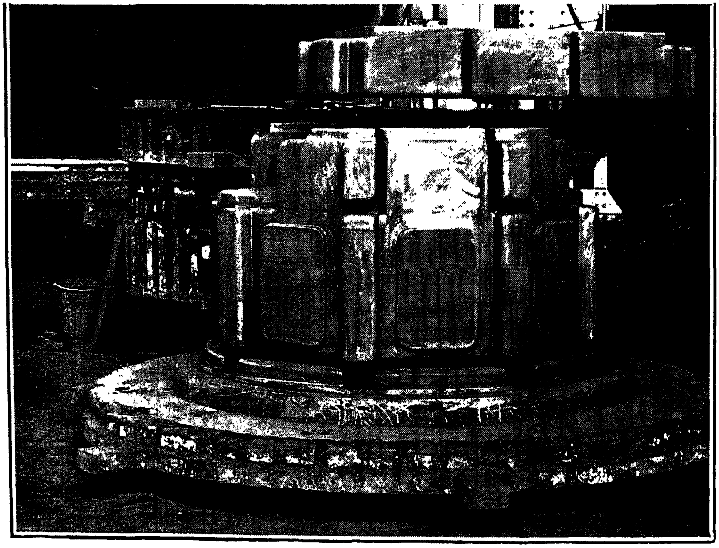


Fig. 111.—Finished Core for Motor Base Casting, with Centre Drawback ready for lowering into position.

The outside of the Mould can be seen standing behind up into the pockets, or cods, E, shown in the half-section B B in Fig. 104. All the loose pieces and brackets are set in position, and the cods, E, built up. As these are to be practically covered with metal, they must be vented well, by means of cinders and pieces of straw. A separate core is now made, running right across the middle of the main core between the L-shaped brackets, this method being necessary, because the brackets have to be removed and finished. The core can be seen hanging from the crane in Fig. 111. After sweeping up the face with the strickle, this is removed, and the positions of the windows, and of the cores which form the inner sides of the vertical columns, are marked round the main core. When the bottom segments have been taken out, these cores can be quickly built on to the body by means of frame boxes, the mode of operation being illustrated quite clearly in Fig. 110. The spindle and runner gates are withdrawn, the long core running across the main core is lifted out, the brackets and ribs are removed, and this portion of the mould is ready for stoving. After sweeping up the top plate, in which are bedded two thin facing pieces, the construction of the mould is complete. Before removing

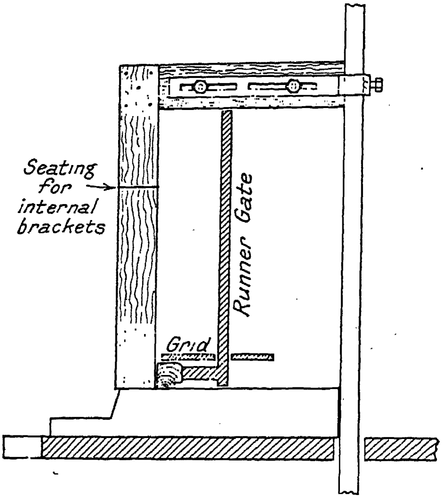


Fig. 109.—Early Stage in Construction of Core

the spindle, a centre-line has to be cut across the outside circular guide, in relation to the facings. When spacing out these, it is essential to arrange them, so that, when the top plate is closed on to the mould, the lugs used for bolting down come over those on the bottom plate.

After the various parts of the mould have been dried thoroughly, they are dressed and blacked, and the cores to form the recess that runs round the bottom of the casting are pushed under the overhanging portion of the main core, and held down at intervals by single studs. The long core running across the main core is next lowered in, and the mould should now be returned to the stove to dry the blacking. In Fig. 111, the recess cores are seen in position, and the long core is being lowered on to its seating. Little need be said about the final closing, but it may be pointed out that the window-frame core-box is made about $\frac{3}{32}$ in. shallow, in order to give a clearance, so that the outside portion of the mould will pass over the core without damage. During the finishing of the core, a clearance should also be cut off the upper edge of the bottom seating, to prevent crushing. The particular job was cast without being rammed round, and the three rows of bricks between the plates not supported by dabbers—and shown clearly both in Figs. 110 and 111, in the outside part of the mould, standing behind the core—were held during casting by bolting a mild steel band round them.

CHAPTER VIII

THE METALLURGY OF CAST IRON

Probably few foundrymen are unfamiliar with the processes involved in the smelting of iron ore in the blast furnace, and, as these are fully described in a large number of textbooks, there should be no need to discuss them here. The requisite metallurgical knowledge must also be assumed. It may be useful, however, to describe briefly the varieties of pig iron, which constitute the raw material of the founder.

The Grading of Pig Irons. The varying quality of the blast furnace product, from white to grey iron, is caused by the condition of the carbon, which occurs either in the free state, as graphite, or combined, as carbide of iron, Fe_3C, known as cementite. In most irons, it occurs partly in each state. When the carbon is chiefly free, the pig iron shows a fracture which is dark grey or nearly black in colour, being known as grey iron. Here the graphite occurs in thin plates, with their long axes at right angles to the cooling surface, constituting cleavage planes. When the carbon is all combined, the fracture is silvery white. Iron which is partly grey and partly white is known as mottled. The quantity of carbon separating in the free state depends chiefly upon the content of silicon, increase in the proportion of this constituent leading to the production of irons which are progressively more grey, soft and weak. This gradation is expressed in practice by means of a series of numbers, as from 1 to 4, and then mottled and white, denoting irons which at first are soft and open in fracture, but contain progressively less silicon, manganese and graphite, and more sulphur and combined carbon, throughout the series, thus becoming gradually harder and more close in grain, until, in white iron, an extremely hard and brittle product is obtained. Fracture is clearly a general guide to composition, but it is an uncertain one, for irons of the same kind, with apparently the same fracture, have frequently very different compositions, while, if the irons are from different sources, diagnosis

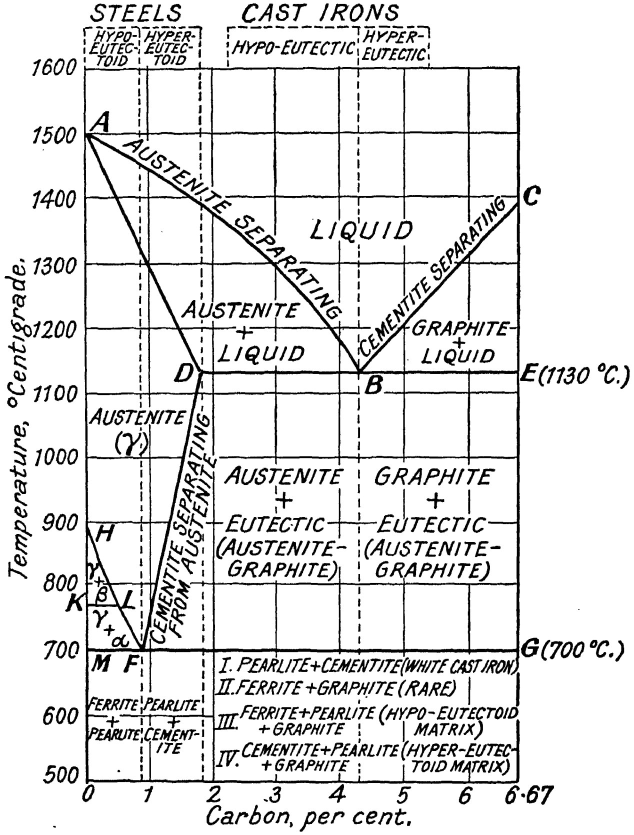

STEELS
CAST IRONS
HYPO-EUTECTOID
HYPER-EUTECTOID
HYPO-EUTECTIC
HYPER-EUTECTIC
Temperature, °Centigrade.
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
A
C
D
B
E (1130 °C.)
G (700 °C.)
H
K
L
M
F
AUSTENITE SEPARATING
CEMENTITE SEPARATING
LIQUID
AUSTENITE + LIQUID
GRAPHITE + LIQUID
AUSTENITE (γ)
CEMENTITE SEPARATING FROM AUSTENITE
γ + β
γ + α
AUSTENITE + EUTECTIC (AUSTENITE-GRAPHITE)
GRAPHITE + EUTECTIC (AUSTENITE-GRAPHITE)
I. PEARLITE + CEMENTITE (WHITE CAST IRON)
II. FERRITE + GRAPHITE (RARE)
III. FERRITE + PEARLITE + GRAPHITE (HYPO-EUTECTOID MATRIX)
IV. CEMENTITE + PEARLITE + GRAPHITE (HYPER-EUTECTOID MATRIX)
FERRITE + PEARLITE
PEARLITE + CEMENTITE
0
1
2
3
4
5
6
6·67
Carbon, per cent.

FIG. 112.—THE IRON-CARBON CONSTITUTIONAL DIAGRAM

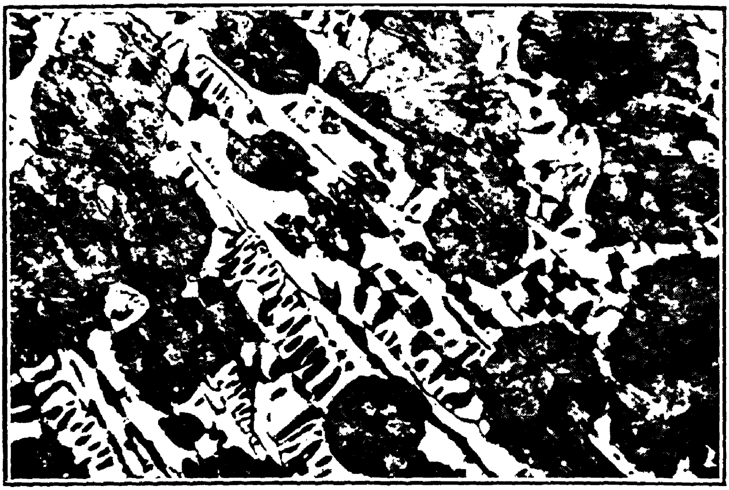
by fracture becomes increasingly doubtful. Again, the system of numbering differs from one district to another, so that a particular number may represent totally different fractures, and it is obvious that indications based on fracture must invariably be confirmed by analysis, or castings of consistent quality cannot be produced.

The Iron-Carbon Constitutional Diagram. If one's practice is to be successful, it is necessary to have knowledge of the rather complicated reactions which occur during the cooling of iron from the molten state down to that of the atmosphere. The constitutional diagram for the iron-carbon alloys is shown in Fig. 112. As will be seen later, two separate diagrams are really involved, but these have for convenience been combined in one figure. The binary system is actually that of iron and iron carbide, or cementite, which contains 6·67 per cent. of carbon. The steels are usually considered to contain up to 1·8 per cent. of carbon, a figure which also represents the maximum solubility of carbon in iron, to produce the solid-solution constituent known as austenite. The carbon content of steel may exceed 2 per cent., however, in some circumstances, but, with this proportion of carbon, the material really begins to come into the classification of cast iron. The cast irons may be considered as the iron-carbon alloys which contain from about 2½ to 4½ per cent. of carbon, although the figure may exceptionally be either lower or higher. In the cast irons, and to a lesser degree in the steels, the influence upon the constitutional diagram of constituents other than iron and carbon cannot be disregarded. Thus, by reason of the presence of a considerable proportion of silicon, commercial cast irons slowly cooled contain more graphite than pure iron-carbon alloys with the same carbon content, while the graphitising effect of silicon is opposed by that of sulphur, these matters being discussed further later.

In cooling from fusion, the liquidus curve is A B C, and the solidus curve A D B E. Along A B, alloys containing less than 4·3 per cent of carbon reject austenite from the liquid, the composition of the solid varying along A D. Along C B, alloys containing more than 4·3 per cent. of carbon reject cementite from the liquid, the constant composition of the crystallising solid being indicated by C E. The point B represents the separation of an austenite-cementite eutectic, containing 4·3 per cent. of carbon, at a temperature of 1130° C. But, at this temperature, cementite is generally unstable, decomposing, soon after solidifying, into iron plus graphite. The area C B E thus indicates, not the existence of crystallised cementite in conjunction with liquid metal, but of graphite plus liquid; while the eutectic, instead of being austenite-cementite, is in reality austenite-graphite. It is the lack of malleability due to the breaking-up of the continuity of the metal by the brittle films of graphite which is so typical a feature of ordinary grey cast iron.

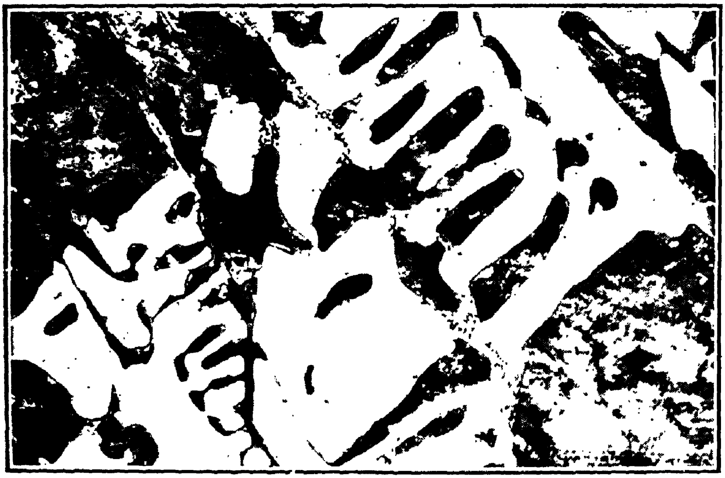
We have seen that the carbon in cast iron can exist either in the free or the combined state, frequently as a mixture of the two. It is possible to obtain, from the same melt, either white or grey iron, by a variation in the rate of cooling, although the commercial varieties known as white, mottled and grey, respectively, usually vary in ways other than in the condition of the carbon. The type of structure produced depends chiefly upon the rate of cooling and the content of silicon, but other elements also have some influence. A slow rate of cooling and a high content of silicon tends to cause graphitisation. A rapid rate of cooling and a high content of sulphur hinders this effect, the production of white iron being promoted. Even when the metal contains much silicon and little sulphur, rapid cooling may produce white iron. Similarly, it may contain so little silicon, or so much sulphur, that the casting is white even after prolonged cooling.

The Steels. For a proper appreciation of the solidification of cast iron, it is necessary to consider briefly the left-hand lower portion of the diagram, concerning the steels. Here the line D F, running down to the left, denotes the solid solubility of cementite in iron, which decreases as the temperature falls, cementite being continuously precipitated until the residual solid solution has reached the temperature of 700° C., and the composition F, representing about 0·85 per cent. of carbon. At this temperature and composition, the residual austenite is converted, with considerable evolution of heat, into a mixture of ferrite and cementite. The areas H K L and K L F M, delimiting temperatures and compositions at which the solid iron varies in structure and properties, need not concern us. It will be sufficient to note that, along the lines H L and L F, iron is re-crystallising from the solid austenite; while along D F, cementite is re-crystallising, until, in either case, the remaining solid solution has reached a concentration of 0·85 per cent. of carbon. The two branches



(× 100 diam.)

FIG. 113 (*a*).—WHITE CAST IRON



(× 400 diam.)

FIG. 113 (*b*).—WHITE CAST IRON

To face p. 187]

in question clearly correspond to the two branches of the liquidus curve where an alloy is solidifying from fusion to produce a eutectic, and the point F is known as a eutectoid point, the constituent produced at 700° C., on reaching the line M F G, being termed a eutectoid. Thus the iron-carbon eutectoid is an intimate mixture of crystals of pure iron, or ferrite, and carbide of iron, Fe_3C, or cementite, composed, in steels which have cooled sufficiently slowly, of alternate lamellæ of these two constituents. The cementite is much harder than the ferrite, and, on polishing, is left in relief, so that the surface consists of alternate ridges and furrows, which, when illuminated obliquely for microscopic examination, operate as a diffraction grating, giving rise to the iridescent colours characteristic of mother-of-pearl, where they arise in the same manner, the name, pearlite, having been applied to the eutectoid for this reason. It will be clear that steels containing less carbon than 0·85 per cent. will consist when cold of free ferrite and pearlite, and those with more than 0·85 per cent. of carbon, of free cementite and pearlite, the same constituents being also found, as will be seen, in the cast irons.

The White Cast Irons. An example of white cast iron is seen in Fig. 113 (*a*) (× 100 diam.) and (*b*) (× 400 diam.). In the solidification of this iron, austenite separates until the remaining liquid has reached the composition of the austenite-cementite eutectic, when it solidifies. In this case, the diagram in Fig. 112 requires modification, by the substitution of the word " cementite " for " graphite " in all the four places where it occurs in the areas C B E and F D E G. On further cooling, the primary austenite rejects more cementite along D F, this tending to deposit on the cementite crystals of the eutectic, so that the quantity of cementite increases, and that of the austenite diminishes. The remaining primary austenite reaches at length composition F at 700° C., and is converted into pearlite; as also is each small austenite crystal in the eutectic. The final structure, shown in Fig. 113, thus consists of large rounded masses of dark pearlite—having their main axes at right angles to the surface, and representing the original skeletons of primary austenite—

set in a ground mass of pearlite and cementite, corresponding to the original austenite-cementite eutectic. The marked disparity in the sizes of the two kinds of pearlite grains is thus readily accounted for. The hardness and brittleness of white iron are caused by the large proportion of cementite. White iron is used for certain duties—as for impellers, liners and other wearing parts of pumps dealing with gritty materials —where a high resistance to wear is the chief requisite. In the form of a hard surface layer, supported by a tough backing of grey iron, it is used for chilled rolls ; and it is the first stage in the manufacture of malleable cast iron, these purposes being dealt with more particularly in Chapter X.

The Grey Cast Irons. Graphitisation may be considered as the normal process in the solidification of iron, complete physico-chemical equilibrium being only reached when the cementite has been entirely transformed into a mixture of iron and graphite. The persistence of white iron, under certain conditions, as such, is denoted by the use of the term " metastable " to describe this condition, a condition in which, incidentally, many industrial alloys find their chief employment. Although grey iron is thus more stable than white iron, it is not completely so, for it almost invariably contains some combined carbon. The chief factors which decide whether an iron shall be grey or white have already been discussed, but others play some part. For example, a high content of total carbon must tend to promote graphitisation. With a content of carbon which is sufficiently great, free cementite may separate along the line B C, while, after solidification, a higher proportion of the austenite-cementite eutectic must be found. But the quantity of free carbon liberated varies with the quantity of metastable cementite which has previously been deposited, and thus a higher carbon content must tend towards the production of a larger proportion of graphite. This is verified in practice, and Fig. 114 shows the relation between the proportion of total carbon, and of graphite, for a large number of irons in the authors' practice, where the dependence of the one figure upon the other is unmistakable. Graphite is the determining factor in the physical properties of grey cast iron, and thus its character and distribution, and the methods of controlling these, have for some time been receiving close attention, these questions being discussed more fully later. The process of graphitisation takes place chiefly, but not entirely, immediately after solidification, the alloy afterwards tending very largely, but not exclusively, to follow the metastable method of cooling, as with the steels. But the cementite

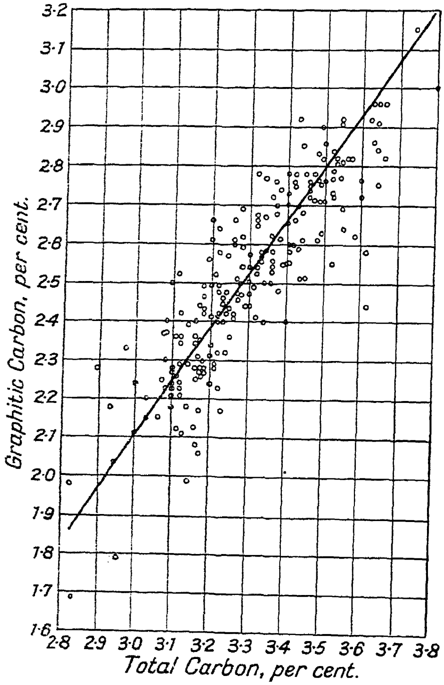
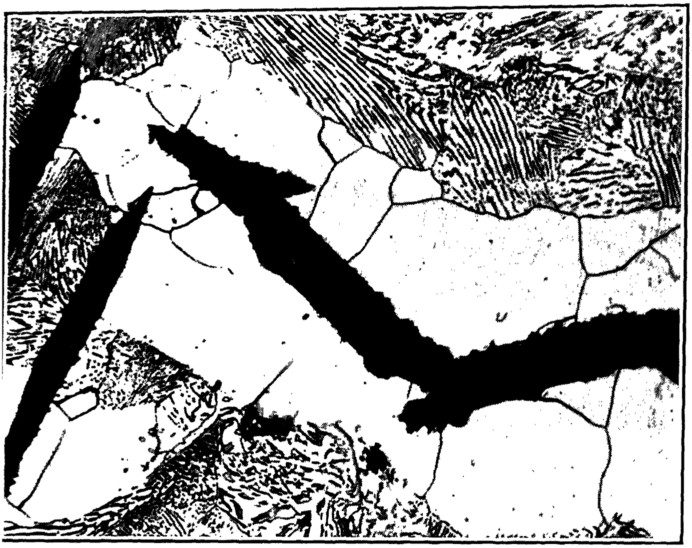


FIG. 114.—THE RELATION OF GRAPHITIC CARBON TO TOTAL CARBON IN DIFFERENT IRONS

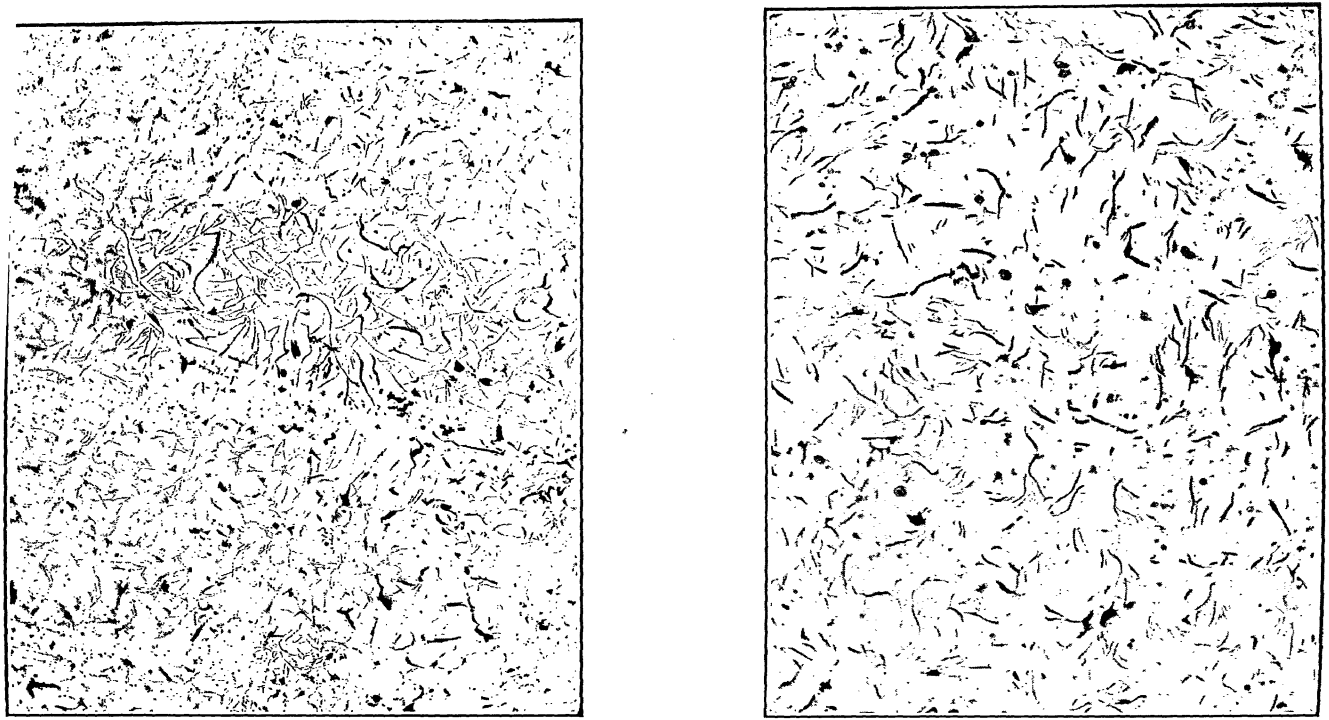
separating at a later stage, as with that deposited on solidification, may also be transformed into a mixture of ferrite and graphite. Even when the residual solid solution is finally converted, at 700° C., into ferrite and cementite, this cementite may also be converted, or may partly be converted, and partly persist, as one constituent of the laminated pearlite. The factors previously mentioned will determine which of these reactions is most completely carried out. Thus, cast iron slowly cooled should consist of flakes of graphite, set in a matrix whose composition varies with the proportion of combined carbon, and consists of ferrite and pearlite in irons with less than 0·85 per cent. of combined carbon (hypo-eutectoid); pearlite only in those containing 0·85 per cent. of combined carbon (eutectoid); and pearlite and cementite in those containing more than 0·85 per cent. of combined carbon (hyper-eutectoid). The presence of various impurities may lead to the production of an all-pearlite matrix, however, with less than 0·85 per cent. of combined carbon. Thus, cast iron resembles steel with which a quantity of graphite flakes have been mixed, these inclusions being responsible for the absence of ductility and the comparatively low strength of cast iron when compared with steel. Apart from the effect of the graphite—which is discussed below—the strength and hardness of hypo-eutectoid irons increase with the content of pearlite, and decrease with that of ferrite. Since pearlite is some 2½ times as strong as ferrite, this would be expected. Therefore irons which are mainly ferritic are soft and weak, and irons which are mainly pearlitic are hard and strong, a characteristic feature of all the high-duty irons being their pearlitic matrix. Fig. 115 is of a weak iron, containing 2 per cent. of silicon, with a matrix of ferrite, the featureless white constituent, having well-marked boundaries, surrounding the graphite flakes. The sides of the illustration show laminated pearlite and the phosphide lakes. Fig. 130, at the same magnification, is of Lanz Perlit iron, having a matrix of fine-grained pearlite.

Variation in Type of Graphite. The solubility of cementite in molten iron increases with temperature. A 2 per cent. silicon iron can dissolve 3·7 per cent. of carbon when just liquid, and 3·95 per cent. at 1480° C., a maximum cupola temperature. For each temperature, there is a definite maximum solubility. If this concentration of carbon is exceeded, as is possible in metal cooling from a higher temperature, the excess cementite must be thrown out of solution, and will dissociate into iron and graphite. Although the saturation limit of cementite in molten iron is not usually exceeded, and therefore no graphite is set free, there are



(× 400 diam.)

FIG. 115.—SOFT CAST IRON, SHOWING GENERAL STRUCTURE



(*a*) From Wall, ¾ in. thick. (*b*) From Head, 7 in. in diameter.

FIG. 116.—VARIATION IN GRAPHITE IN DIFFERENT PARTS OF A DIESEL COMPRESSOR CYLINDER CASTING (× 20 *diam.*)

occasional instances of irons, with a high content of carbon and silicon, in which so much graphite may be liberated in the molten iron that it will form a thick scum on the surface, being known to the foundryman as "kish." Kish is not described as "primary graphite," the use of this term being limited to that resulting from the dissociation of the cementite immediately after solidification, or that liberated, at slightly lower temperatures, by the decomposition of the cementite which separates from the austenite along the line **D F** of the diagram. Secondary graphite is that resulting from the transformation at 700° C.

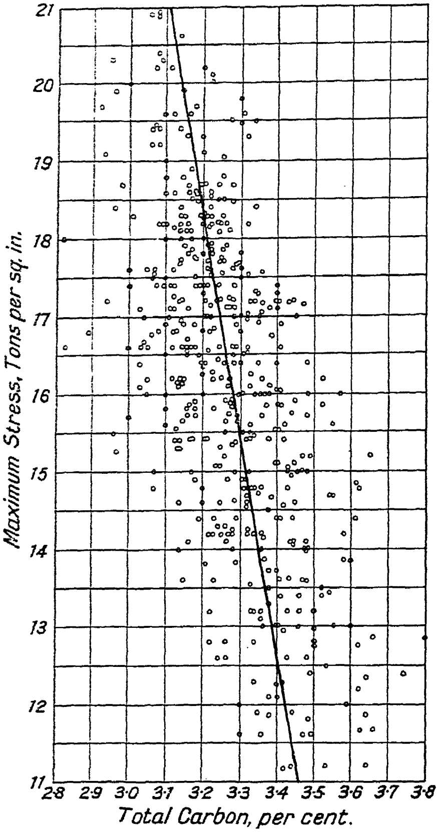


FIG. 117.—THE RELATION BETWEEN TOTAL CARBON AND TENSILE STRENGTH IN DIFFERENT IRONS

The flakes of kish are usually straight, elongated and massive; those of the primary graphite being shorter, more curly and branching, while the secondary, from the pearlite decomposition, is fine and lamellar. These differences emphasize the point that, apart from the quantity of graphite, its form is important. Of two irons having the same content of graphite, that with long straight flakes must—other things being equal—be weaker than that with short curly flakes, and the variation in graphite form in different irons in practice has an important bearing upon their quality and reliability.

Variation of Graphitisation with Rate of Cooling. The quantity of graphite set free during cooling must depend on the composition and on the rate of cooling, more graphite being produced if the rate is slower. A lower pouring temperature must therefore retard graphitisation. Large castings must be more graphitic than small ones cast from the same metal. Of two castings of the same size, that containing the most silicon will probably contain the more graphite. Since the inside of a casting cools more slowly than the outside, it will show larger and coarser flakes of graphite, and also a pearlite of coarser grain, its strength being correspondingly diminished. Fig. 116 (*a*) and (*b*) shows, at a magnification of 20 diameters, the varying graphite in the heaviest and lightest portions of a Diesel compressor cylinder, made in a special iron, the corresponding analysis figures being as follows:—

Section	Wall (¾ in. thick)	Feeding Head (7 in. dia.)
Combined Carbon % ..	0·60	0·40
Graphitic Carbon %	1·99	2·16
Total Carbon %	2·59	2·56
Silicon %	1·74	1·74
Sulphur %	0·144	0·144
Phosphorus %	0·18	0·18
Manganese %	0·79	0·79
Tensile Strength, tons per sq. in.	17·8	11·0

The much larger graphite flakes break up the structure of the metal to a considerably greater degree, and the reduction of strength from nearly 18 down to 11 tons per square inch is thus readily explicable.

The Effect of Different Constituents in Cast Iron. The influence of the various constituents may be summarised, as follows :—

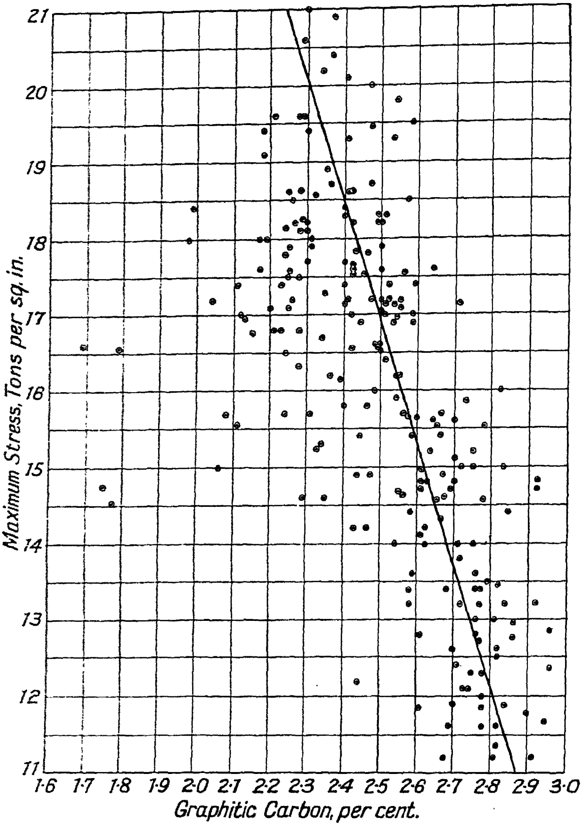


Fig. 118.—The Relation between Graphitic Carbon and Tensile Strength in Different Irons

Carbon lowers the melting point and increases the fluidity of the metal. A higher carbon content means more graphite, the direct relationship between these being well shown in Fig. 114. Since the breaking up of the continuity and therefore the cohesion of the metal must depend—other things being equal—upon the quantity of graphite present, the tensile strength of the metal must vary inversely, both with the content of total carbon (Fig. 117) and with the content of graphite (Fig. 118), these graphs affording excellent confirmation of the theoretical deductions. Since there is a definite relationship (Fig. 119) between the amount of carbon in the cupola charge and that found in the resulting iron, the average proportion in the charge should be kept low, if high strength is required. But carbon may also exist as combined carbon, the strength varying directly with the content of this constituent, up to a proportion of 0·95 or so per cent., as shown in Fig. 120. Here the variation in graphite is perforce neglected, but the general trend of the line is quite clear, and it should be said that it has been drawn as closely as possible through the averages for the various figures, and not at random. With a combined carbon content over about 0·95 per cent., the metal becomes harder, less machinable and weaker, as the free cementite increases. In general, reducing the carbon content of the iron results in a corresponding increase in tensile and transverse strength, and also in shock resistance, the deflection figure showing little variation; but the shrinkage and therefore the general tendency towards unsoundness increase in a parallel manner, as also the foundry difficulties. As the carbon content is progressively less than about 3 per cent., it is necessary to provide larger runners and risers, which with a carbon content of 2·5 per cent. should approach in dimensions to those used for steel castings.

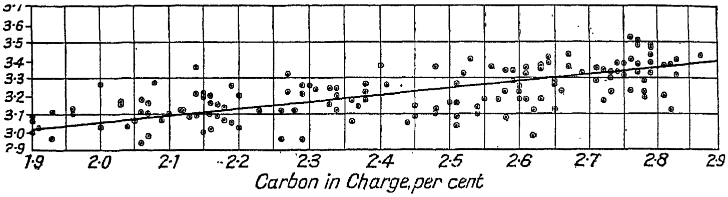


FIG. 119.—THE RELATION BETWEEN CHARGE CARBON AND FINAL CARBON IN DIFFERENT CASTS

Silicon occurs in cast iron chiefly as the silicide, FeSi, dissolved in the ferrite. By its effect upon the carbon, it acts indirectly as a softener, promoting graphitisation, fluidity and soundness, but diminishing the strength and hardness. Its graphitising effect is opposed by that of sulphur, referred to below. It is directly a hardener, as seen in the very hard and brittle high-silicon acid-resisting alloys. In ordinary grey iron castings, the silicon must be proportional to the mass and section of the castings. Insufficient silicon may result in castings which are white, hard and brittle. By casting in a hot mould, so as to retard the rate of cooling, much lower proportions of silicon may be used, while still obtaining a perfectly grey iron of high-duty quality, this principle being used industrially in the production of Lanz Perlit iron, which shows remarkable toughness and resistance to growth when heated. In ordinary cold-mould castings, maximum tensile strength is obtained by the use of about 1 to 1·3 per cent. of silicon, but in the hot-mould process the proportion may be as low as 0·5 per cent. Since some 25 per cent. of silicon may be lost in passing through the cupola, while sulphur is at the same time absorbed from the coke, re-melting hardens the metal.

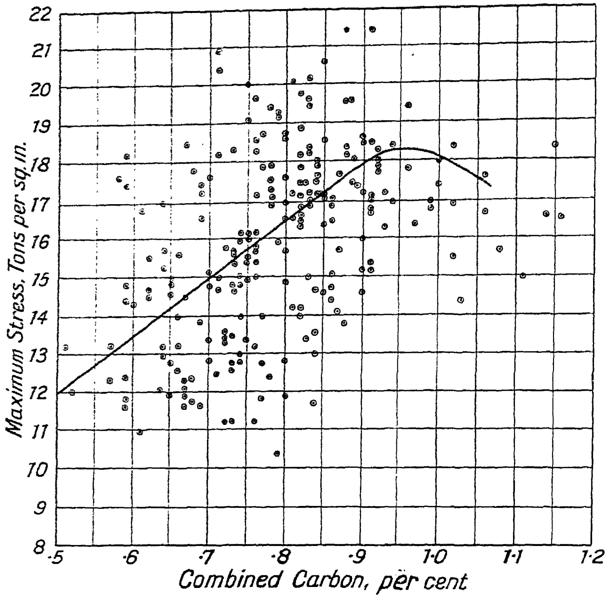


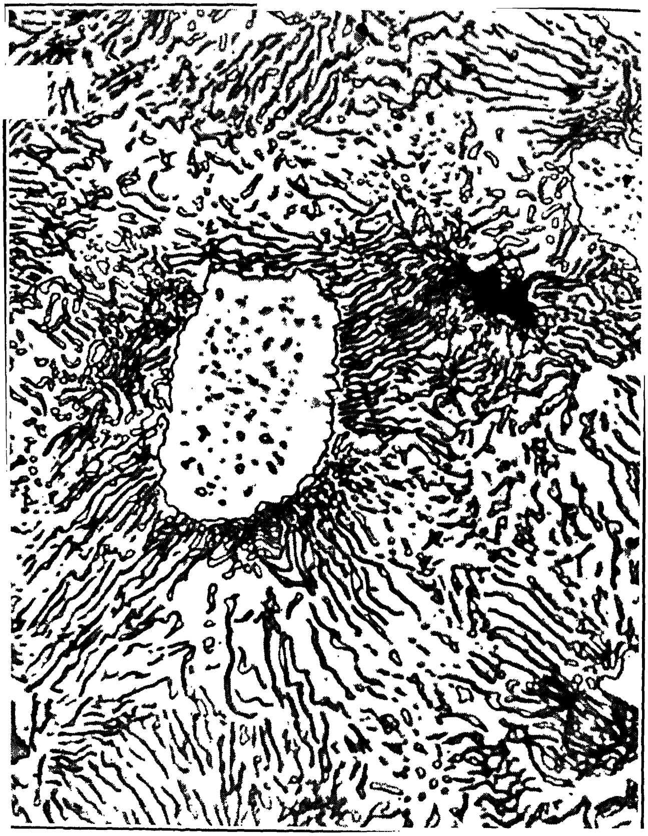
FIG. 129.—THE RELATION BETWEEN COMBINED CARBON AND TENSILE STRENGTH IN DIFFERENT IRONS

Sulphur exists in iron, in the presence of a sufficient proportion of manganese, as manganese sulphide, MnS, or, possibly, as mixed sulphides of iron and manganese. In the absence or deficiency of manganese, iron sulphide will occur, frequently in thin films, which have a weakening effect much greater than their mass would appear to warrant. The inclusions of manganese sulphide—possibly mixed with iron sulphide to some extent—are slate-blue or grey in colour, some examples being shown, magnified 400 diameters, in Fig. 130. The general tendency of sulphur, which is apparently exerted by its presence as FeS, and not as MnS, is to reduce graphitisation, and thus to give rise to an iron which is more sluggish, with higher shrinkage, more unsound and harder. This tendency suggests that sulphur may be a useful constituent in irons required to resist wear. An increase of roughly some 50 per cent. in sulphur content occurs in passing through the cupola, by absorption from the coke.

When charging large quantities of scrap or using sulphury coke, the sulphur content of the resulting metal may be definitely prejudicial to the production of satisfactory castings, a tendency which may be corrected, however, by desulphurisation. Reductions of 50 per cent. in the sulphur content of cast iron containing from 0·10 to 0·15 per cent. of sulphur can readily be obtained by the addition of about 1 per cent. of anhydrous sodium carbonate. This is placed in the bottom of the ladle, the metal, as hot as possible, being then tapped on to it. A vigorous reaction takes place, sodium sulphide being formed, with the evolution of carbon dioxide, the primary reaction being represented as follows:

$$4\,\genfrac{}{}{0pt}{}{\mathrm{FeS}}{\mathrm{MnS}} + 4\,\mathrm{Na_2CO_3} = \mathrm{Na_2SO_4} + 3\,\mathrm{Na_2S} + \genfrac{}{}{0pt}{}{4\,\mathrm{Fe}}{4\,\mathrm{Mn}} + 4\,\mathrm{CO_2}$$

The mechanical agitation also effects a refinement in graphite size, and some removal of gases and non-metallic inclusions, with resulting improvement in quality. After about 5 minutes, the vigour of the reaction subsides, and a soda slag collects on the surface of the metal. When the cupola is being tapped at intervals to collect the necessary quantity, the second and subsequent taps are run through the refining slag, imparting an additional stirring action, promot-



(*E. Leitz, London*)

FIG. 121.—PHOSPHIDE LAKE IN PEARLITIC CAST IRON (× 1500 diam.)

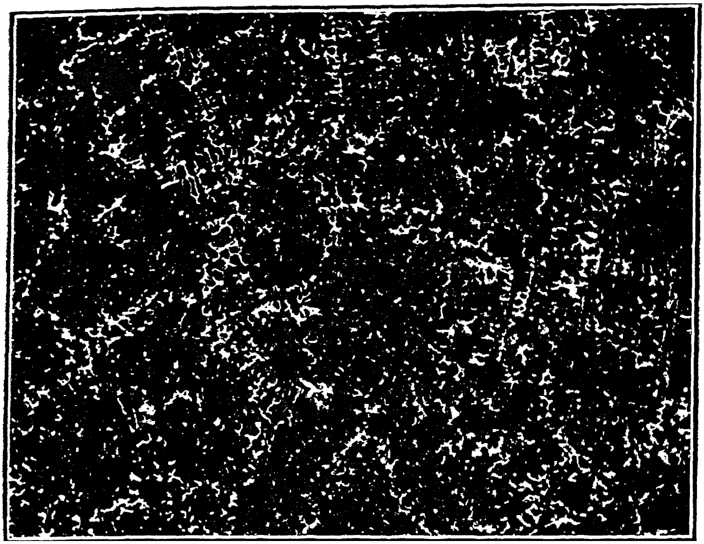
To face p. 197]

ing sulphur elimination. In order to facilitate removal of the very fluid slag, ground limestone, of about three-quarters the weight of the sodium carbonate used, is added, when the slag soon thickens up and can readily be skimmed off. In a recent improvement of the process, the sodium carbonate and the limestone are placed in the ladle together, thus avoiding some of the delay incident to the later addition of the limestone. Soda ash may also be added, in the proportion of $\frac{1}{4}$ to $\frac{1}{2}$ per cent., in the cupola, it being thus possible to fill hand-shanks with treated metal which must be hot, as in pouring malleable castings, where the delay involved in treatment in the shanks, and the subsequent removal of the soda slag, renders this method impracticable. The use of soda ash in the cupola has no very marked effect in reducing sulphur content, unless the slag can be kept sufficiently basic, but it has a mechanically cleansing effect upon the metal, and also reduces carbon pick-up, probably by reason of the slight glaze formed on the surface of the bed coke by the fused soda. In this method, a fused block (4 lb. in weight) is charged on the bed coke, and then $\frac{1}{4}$ to $\frac{1}{2}$ lb. for each cwt. of metal charged. The blocks may either be used whole, or may be broken up into pieces of walnut size and distributed evenly over the charge, with the limestone.

Phosphorus occurs in iron as an iron phosphide, Fe_3P, the content by weight of which is 6·4 times that of the phosphorus. Iron phosphide is one constituent of the $Fe_3C : Fe_3P$ eutectic, which solidifies at 950° C., and persists in white irons down to normal temperature. In grey iron, however, the silicon present causes the carbide constituent to break down into iron and graphite, leaving the phosphide structurally free. A phosphide "lake," in an example of pearlitic cast iron, is shown, at a magnification of 1500 diameters, in Fig. 121. The phosphide constituent occurs frequently as a network round the grain boundaries of the pearlite kernels, as in Fig. 122, of an iron containing 2 per cent. of silicon and 0·80 per cent. of phosphorus. Phosphorus has no appreciable effect on the condition of the carbon, but it reduces the solubility of the iron for carbon, and thus acts indirectly as a hardener, particularly against abrasive wear. Since the phosphide eutectic is the constituent which has the lowest melting point, phosphorus promotes fluidity, and high-phosphorus irons are therefore well adapted for the manufacture of stove and grate castings, and similar intricate work of small section. High-phosphorus castings are, however, very weak and brittle, and 0·60 per cent. of this constituent is a safe limit for good-quality castings, while, in the case of castings subject to shock, or which are required to resist heat, the proportion should be as low as possible.

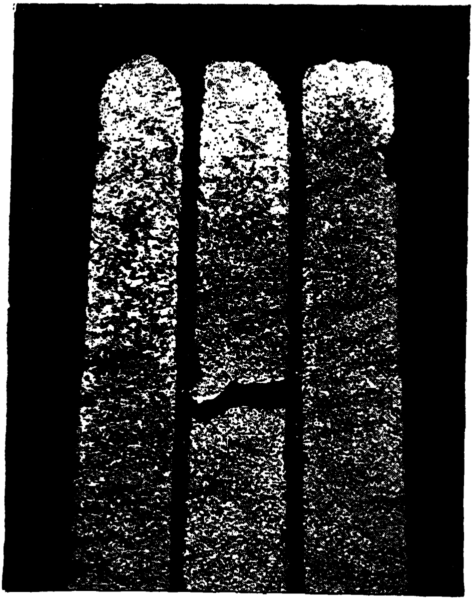
The influence of manganese in cast iron is a debatable one. It seems to act in two different ways, influencing the carbon and sulphur, respectively. It certainly tends to correct the ill-effects of the presence of iron sulphide, and must be present in quantity sufficient to form the rounded particles of sulphide of manganese, instead of the brittle films of sulphide of iron. This may also be advantageous in increasing the resistance to wear. From the work of a number of investigators, it is clear that, within the limits of manganese usually present in commercial irons, *i.e.*, up to about 2 per cent., it does not influence the condition of the carbon, but, when present in greater quantities, it retards graphitisation, and increases shrinkage, chill and hardness, a high content of manganese being thus sometimes recommended for irons required to resist wear. Manganese is said to tend to produce sound castings, this being possibly due to its action in retaining dissolved gases in solution, in bringing about a reduction in the temperature of solidification, and in preventing the formation of iron sulphide.

The Effects of Special Elements sometimes added to Cast Iron. The effect of nickel in cast iron is closely analogous to that of silicon, for it is indirectly a softening constituent, by its influence on the carbon, but its direct effect on the matrix is one of hardening. Which of these two effects is the greater depends to a considerable extent upon the amount of combined carbon present. In the lower proportions, therefore, nickel promotes graphitisation, and reduces chill—although its influence in this respect is only about one-third that of the silicon—and it thus softens the metal in the thinner sections, improving the machinability in places where, by reason of local hardness, this operation has been found very



(× 20 diam.)

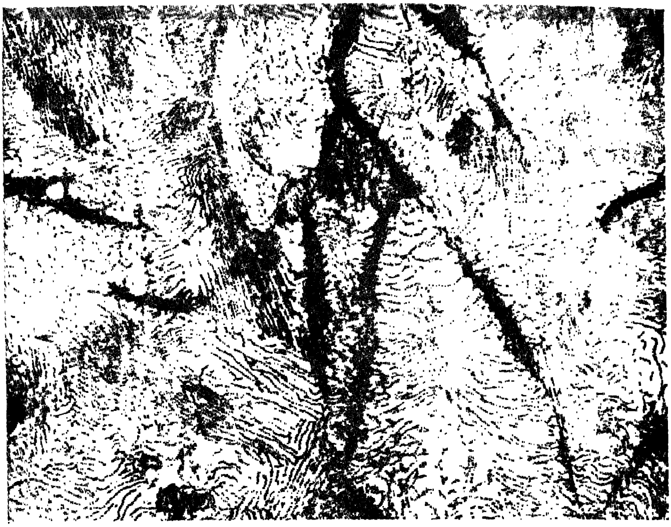
FIG. 122.—PHOSPHIDE NETWORK IN CAST IRON CONTAINING 0·80 PER CENT. OF PHOSPHORUS



Nickel o 1 2 per cent.

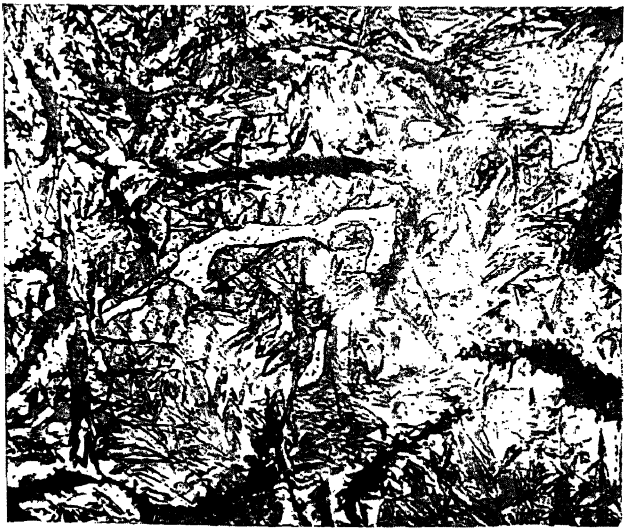
(The Mond Nickel Co., Ltd.)

FIG. 123.—THE EFFECT OF NICKEL ON CHILL



(× 500 diam.) (*The Mond Nickel Co., Ltd.*)

FIG. 124.—PEARLITIC STRUCTURE OF CAST IRON CONTAINING 1 PER CENT. OF NICKEL

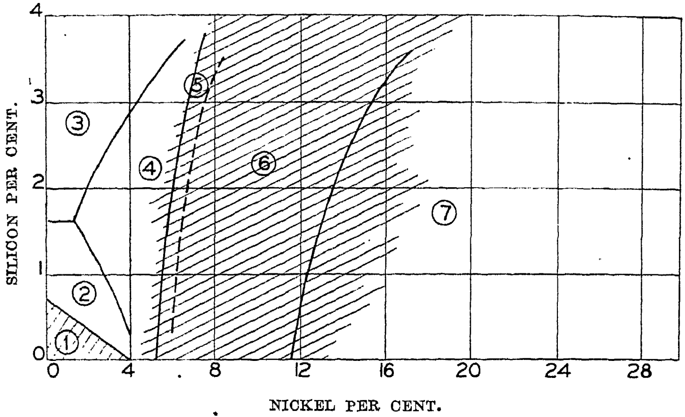


(× 500 diam.) (*The Mond Nickel Co., Ltd.*)

FIG. 125.—MARTENSITIC STRUCTURE OF CAST IRON CONTAINING 5 PER CENT. OF NICKEL

difficult. The effect of nickel in progressively reducing the tendency of low-silicon irons to chill is shown in Fig. 123. The effect of nickel on the heavier portions of a casting differs to a considerable degree from that of silicon. Although both silicon and nickel lead to a gradual reduction of hardness in both the light and heavy sections, the effect of nickel is a more gradual one, the use of nickel thus tending to equalise the hardness in the varying sections to a much greater degree than in the case of silicon. The use of nickel will often successfully correct a previous tendency towards local unsoundness. Irons containing 1 or 2 per cent. of nickel are grey and machinable, the combined carbon being present in a matrix of fine-grained pearlite. Fig. 124 is of an iron containing 1 per cent. of nickel, with such a matrix, which is characterised by excellent resistance to wear. When nickel is thus added, the silicon content should naturally be reduced to a corresponding degree, a 1·65 per cent. silicon iron, containing 1·05 per cent. of nickel being equivalent, on the 1 : 3 nickel-silicon basis, to a 2 per cent. silicon iron containing no nickel.

On increasing the nickel content beyond 2 per cent., or so, the irons become gradually harder, the pearlitic matrix being transformed into one of sorbite, this occurring when the nickel content reaches 3 to 4 per cent. Sorbite is a finer variety of pearlite, in which the two constituents are only separable with difficulty by the microscope. Such irons are still grey, however, and the combined carbon figure may be even lower than in the equivalent low-nickel iron. On increasing the proportion of nickel still further, the hardness continues to increase, reaching a maximum with 5 to 8 per cent. of nickel, on the matrix becoming martensitic. Martensite is a constituent of hardened steels, where it is found as an acicular or interlacing needle-like structure, the needles being often arranged in triangular formation. In steels with a relatively high carbon content, this constituent is of great hardness, so that it will even scratch quartz. Fig. 125 is of an iron with a nickel content of 5 per cent., having therefore a martensitic basis, the acicular formation being clearly shown. Further increase in the nickel content over about 8 per cent. leads to a gradual reduction in hardness, owing to the progressive replacement of martensite by austenite, the solid solution of carbon in γ-iron, which is much softer than martensite. This replacement only takes place gradually, however, and traces of martensite may still exist, even in irons containing 16 to 18 per cent. of nickel. Irons with more than 20 per cent. of nickel contain only austenite. These various alterations in structure with composition are represented in Fig. 126, where the shaded areas indicate the compositions of irons not machinable by ordinary methods. A high-nickel cast iron is shown in Fig. 127. Although this contains chromium also, it is of typical austenitic type, the matrix being a homogeneous solid solution, of character totally different from that of the usual pearlitic irons.



(*The Mond Nickel Co., Ltd.*)

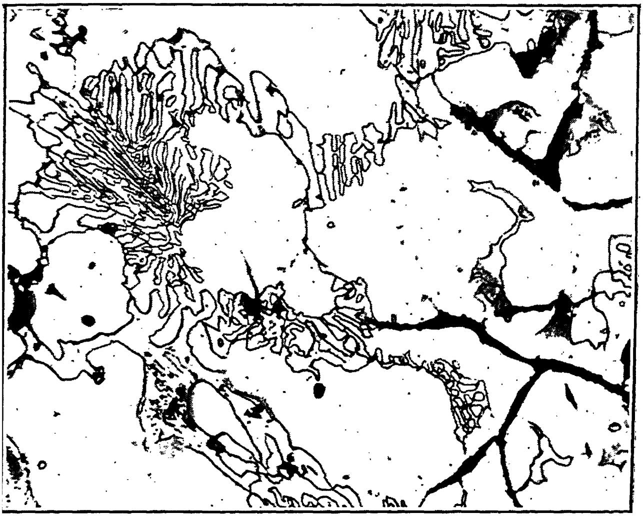
1. Pearlite + Austenite-Cementite Eutectic.
2. Pearlite + Pro-Eutectoid Cementite + Graphite.
3. Pearlite + Graphite.
4. Sorbite + Graphite.
5. Martensite + Graphite.
6. Martensite + Austenite + Graphite.
7. Austenite + Graphite.

FIG. 126.—CONSTITUTION OF NICKEL-SILICON-IRON ALLOYS WITH 3·5 PER CENT. OF CARBON

(Shaded Areas indicate Ranges of Unmachinability)

The nickel cast irons are thus divided into three classes, each with its own field of application, as follows:

1. Those within the pearlitic range, containing from $\frac{1}{2}$ to 2 per cent. nickel, where the nickel effects valuable



(× 400 diam.)

127.—Austenitic Cast Iron, containing 24·3 per cent. of Nickel

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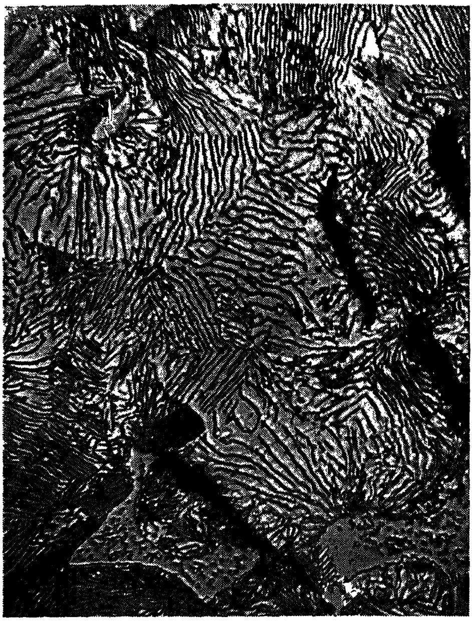
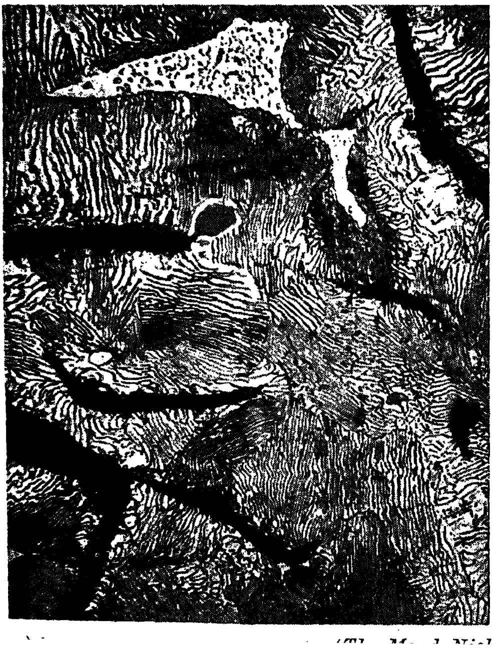


(× 500 diam.) (*The Mond Nickel Co., Ltd.*)
FIG. 128.—CYLINDER IRON, CAST 2·2 IN. DIAMETER



(*The Mond Nickel Co., Ltd.*)

modifications to the structures normally produced, this class being that in the greatest industrial use.

2. The hard cast irons, containing 5–7 per cent. of nickel, used for parts required to resist abrasive wear, the machining of such castings being naturally a special problem.

3. The austenitic irons, containing preferably more than 20 per cent. of nickel, and, frequently, copper, chromium, or both constituents, in addition. These irons have a much greater resistance to corrosion and heat than in the case of ordinary irons, and they are largely used for this purpose industrially.

Up to about 1 per cent. of nickel can be added to molten cast iron without any serious loss of temperature, a suitable form being that of nickel-silicon shot, containing about 90–92 per cent. nickel, 6–8 per cent. silicon, the balance being chiefly iron and carbon. The melting point of this alloy, 1260° C., is much nearer to that of cast iron than in the case of nickel (1452° C.). The shot is best added to the stream of metal tapped from the cupola, the authors' arrangement consisting of a sheet-metal funnel, at the bottom of which is a hole, ½ in. in diameter, closed by a movable plunger. The funnel is supported so that its orifice is about 15 in. above the metal stream, this fall giving the shot enough impetus to force it well into the iron, so as to promote rapid melting. The weighed amount of shot for the quantity of metal being tapped is charged in, and added gradually to the metal stream, by pulling down the wire attached to the plunger. The addition of nickel should begin as soon as the ladle is about 2 in. full, and should be continued at a constant rate until the ladle is about half full. When 2 per cent. or more of nickel has to be added, 50 : 50 ferro-nickel pig, or small pig and plate nickel, can be used in the cupola charge. Small quantities of nickel irons can be melted very conveniently in a crucible furnace. A further method of dealing effectively with larger quantities is to melt in a crucible furnace a small amount of cast iron containing a high percentage of nickel, and to add this, in the correct proportion, when molten, to the partly-filled ladle under the cupola spout.

The effect of chromium in cast iron is to increase the proportion of combined carbon, and therefore the strength, hardness and chilling quality of the metal, its influence being thus the opposite of those of silicon and nickel. Chromium resembles nickel in some respects, however, for it has a hardening and grain-refining effect upon the matrix, and also some tendency towards equalising the soundness and hardness of the light and heavy sections of the casting. Although its hardening properties are such that chromium might well be used by itself in reasonably heavy castings which are required to resist wear, it is not often used alone, but generally in conjunction with nickel, the combination producing irons superior to those resulting from the use of either constituent separately. The chromium offsets the graphitising tendency of the nickel, and the nickel corrects the chilling effect of the chromium. In general, nickel-chromium irons have both graphite inclusions and a matrix of refined character, being thus hard and strong, and resistant to wear by abrasion. Although, when using nickel by itself, the silicon content, as we have seen already, has to be proportionately reduced, this is unnecessary when nickel and chromium are used together, so long as a 3 : 1 nickel-chromium ratio is maintained. The silicon content should, however, be kept on the low side, so as to obtain a maximum grain-refining effect. Fig. 128 shows an ordinary iron, and Fig. 129 is the same, except that 0·85 per cent. of nickel and 0·25 per cent. of chromium have been added, it being naturally desirable to keep the nickel, rather than the chromium, in excess of the ratio in question. Here the pearlite matrix has been definitely refined. Up to 0·90 per cent. of nickel and 0·30 per cent. of chromium can be added to the cupola stream in the manner already described, but the ferro-chrome should be crushed to pass a 10-mesh sieve, the dust being rejected. With larger additions of the alloys, the ferro-chrome, as in the case of the nickel, must be added to the cupola charge in lump form or as chromium briquettes; while nickel-chrome pig irons are now available. Chromium is used, generally to the extent of about 1½ to 4 per cent., in the high-nickel austenitic cast irons, to increase their hardness. If more than 3 per cent. of chromium is added, the castings are more difficult to machine, while with 7 per cent. of chromium they cannot be machined by ordinary methods.

HIGH-DUTY IRONS

It will be obvious that many of the alloy cast irons are produced specifically to meet severe conditions in service, and may therefore be correctly described as "high-duty irons." This term has also come into fairly common use, however, to describe irons of various compositions, and not necessarily alloy irons, but characterised by exceptional strength, so that their employment should enable a corresponding reduction in the size of scantlings to be effected. A quite arbitrary limit for the tensile strength of "ordinary" cast irons would be 15 tons per sq. in. It is of course quite possible, by usual cupola methods, to obtain higher figures, up to 18 tons per sq. in., or more, by charging suitable mixtures, but such irons would be generally regarded as belonging to the "high-duty" class. By using additions of nickel and chromium, figures up to 20 tons per sq. in. can be obtained if desired. Strengths greater than this can be consistently obtained only by special means, as will be referred to later. All these figures apply only to smaller castings, for which the S bars (0·875 in. in diameter) of B.S.S. No. 321 would apply, for the strength of cast iron is proportionately lower as the diameter of the test bar increases.

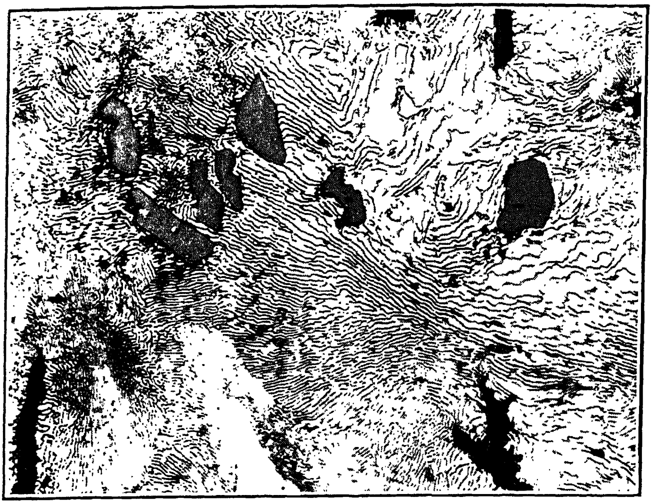
"Semi-Steel." One of the earliest of improved irons was the "Semi-Steel" developed during the War. Incidentally, this term, implying as it does a product intermediate in properties between those of iron and steel, is most misleading, and its use should be abandoned. Semi-steel is actually only cast iron in the manufacture of which some proportion of steel has been used, and its quality may be good, indifferent or poor, according to the success of the technique employed. In any case, the identity of the steel is completely lost after carburising and melting in the cupola, and it is quite impossible to discover, by the analysis of an iron, whether steel has been used in the charge, or not. Even when properly made, it is merely an improved cast iron, in which the addition of a proportion of steel has enabled one to reduce the quantity of carbon in the charge, and therefore in the final casting, the other impurities present—phosphorus in particular—being similarly diluted with advantage. In the production of high-duty cast irons, referred to below, steel is thus a useful addition to the charge, but it is in reality only this indirect and diluting effect which renders it so ; and irons of equivalent quality can generally be made by using a mixture of low-carbon pig irons and scrap. This method is dearer, however, and low-carbon irons can more economically be made by employing suitable proportions of steel scrap. It will thus be clear that the name, Semi-Steel, has no virtue as representing a product of any particular quality, but requires supplementing by reliable test figures of the material in question, before any significance can be attached to it.

High-Duty Irons in General. The alloy cast irons coming under this designation have already been dealt with. It is now necessary to discuss those other high-duty irons, which frequently contain no special constituent, but possess properties markedly superior to those of ordinary irons. These irons are frequently known as " pearlitic " cast irons, a title not altogether appropriate, because practically all cast iron, no matter how inferior its quality, contains some proportion of this constituent. They are so designated, however, because, when properly constituted, they are composed chiefly of pearlite. These irons are manufactured by keeping the carbon content of the iron, and therefore that of the graphite, on the low side ; by refining the graphite ; by using only a low proportion of phosphorus—a constituent which is undesirable where a high resistance to shock or heat is required—and finally, by so fixing the content of silicon, whose proportion must vary with the temperature of the mould, as to avoid an excess, either of ferrite or cementite, over those required to give rise to pearlite only. The mechanical quality of pearlitic cast iron should thus resemble somewhat that of steel having the eutectoid proportion of carbon, except that a variation is naturally introduced by the presence of the graphite inclusions, the strongest irons being those in which the number and size of these inclusions is a minimum, and the grain of the pearlite ground mass is as fine as possible. Such irons show generally a high strength, and a high resistance to wear, shock and heat, these properties being found, to a greater or lesser extent, in various special irons, as Lanz Perlit, Thyssen-Emmel iron, Krupp's Sternguss and others. It will be appreciated that the term "high-duty" may be applied, both to irons having unusual strength, and to those showing good heat resistance, the one property not being necessarily a consequence of the other.

High-duty irons are produced in practice by various distinct processes, some of these being proprietary. Several of them aim specifically at refining the graphite, by charging a mixture of low silicon irons, which, if cast under normal conditions, would be mottled or white, and useless, but is so treated as to cause the separation of sufficient fine-grained graphite to ensure that the casting will be grey and machinable. The necessary separation of fine-grained graphite in an iron which would normally cast white may be effected by pre-heating the metal in the cupola or other furnace, so that the mould becomes heated to a high temperature, while the metal, after an initial rapid cooling, cools slowly through the critical range; by running excess metal through the mould, so as to ensure mould pre-heating and retard cooling, or by pre-heating the mould to receive metal cast at normal temperatures, the last method, which can be controlled with great certainty, possessing obvious advantages. Alternatively, the production of grey iron from a mixture, which would otherwise cast mottled or white, can be achieved by the addition of graphitising compounds to the ladle, this method, known as "inoculation," being obviously one capable of exact control. Among such graphitising additions are calcium silicide, as used in the Meehanite process, and ferro-silicon and F. nickel shot, as used in the Ni-Tensyl process, both of these methods being referred to later. Ni-Tensyl is strictly an alloy cast iron, but can conveniently be discussed in the present section.

Lanz Perlit Iron. This proprietary iron has an extended application. The principle of the process is now generally understood. It consists, in brief, in pouring into a sand mould which has been heated to a pre-determined temperature, molten cast iron of a pre-determined composition. The composition is varied according to the thickness of the section and the mass of the casting. So also is the mould temperature. By a suitable balance between composition and mould temperature, one can obtain what amounts to an equalisation in the rate of cooling throughout the light and heavy sections alike. The tendency to graphitisation in the heavy sections—where the effect of heat from the mould walls, in relation to the mass of the metal, is less—is diminished by using a low content of silicon. The tendency to graphitisation in the light sections is increased by the action of the hot mould walls in close proximity to each other. The mould temperature regulates cooling in the light sections, and the silicon content that in the heavy ones. Herein lies one of the fundamental differences between Lanz Perlit and any cold-mould grey iron. The latter cools at varying rates, according to the varying thickness of section, and the usual inequalities in structure are liable to present themselves. In the heavier sections of a cold-mould casting, the graphite flakes must inevitably be more massive, and the strength of the material correspondingly lower than in the lighter sections. The heavier sections have thus a decidedly coarser fracture, and, when denseners are not employed, may often be definitely unsound. A casting in Lanz Perlit iron, made from the same pattern, will—if the composition and mould temperature have been suitably balanced—be the same throughout, with no signs of porosity, nor even a variation in structure. Fig. 130 shows the fine-grained structure typical of this iron, which is characterised by a comparatively high malleability, both hot and cold, and a corresponding toughness and resistance to shock.

An outstanding advantage of the Lanz Perlit process is that the slow and controlled cooling involved in casting in a hot mould ensures a freedom from contraction stresses which cannot be obtained by casting in a cold mould. It is thus unnecessary to anneal important castings in this iron, as may be often necessary for equivalent castings made in the usual manner. This self-annealing effect is a considerable factor in reducing failures due to cracking in service, making this material particularly suitable for such parts as Diesel engine pistons and cylinder heads, much of the success



(× 400 diam.)

Fig. 130.—Lanz Perlit Iron

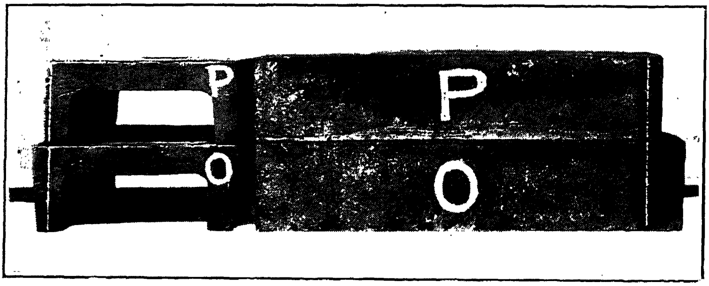


Fig. 132.—End and Side Views of Castings (Channel Section) used in Growth Tests at 850° C.
P = Perlit Iron. O = Ordinary Iron.

[To *face p.* 206

obtained with these parts in service being due to this property. The strength of Lanz Perlit varies, as that of any iron, with its total carbon and silicon contents, but this iron is now being made regularly to a specification which requires, in the as-cast state, *i.e.*, without heat treatment, a minimum tensile strength of 20 tons per sq. in., and a minimum transverse modulus of rupture of 33 tons per sq. in., no difficulty being found in maintaining a good margin, of say 10 per cent., above these figures.

Figures showing enhanced tensile and compressive strength, shock resistance and hardness can be obtained from any iron by heat treatment. The comparative figures for a typical example of Lanz Perlit iron (Total carbon, 3·10 per cent.: silicon, 0·80 per cent.) as cast, and after heat treatment (Oil-hardened at 850°; tempered at 450°C.) were respectively as follows:

	As Cast	*Heat-Treated*
Tensile Strength, tons per sq. in ..	19·2	28·6
Compressive Strength, tons per sq. in.	59·6	95·0
Repeated Impact (Mohr & Federhaff M/C)	4,170	14,120
Brinell Hardness	217	375

As heat-treated, the material was hard and tough, but machinable by ordinary tools at speeds comparable with those for normal Lanz Perlit.

The comparative shock resistance of Lanz Perlit in the as-cast state may be indicated by reference to figures obtained in the standard 120-ft. lb. Izod Machine, but using, instead of the ordinary test piece, as for steel, the modified test piece for cast iron, devised by McRae Smith.* Here the bar, 1 in. in diameter, has a semi-circular groove, with a radius of 0·05 in., machined all round the periphery, the effective diameter at the bottom of the groove being thus 0·9 in., while the striking distance is 22 mm. above the middle of the groove, as usual. Under these conditions, a large number of tests show approximate values of 17-20 ft. lb. for Lanz Perlit, compared with about 8-11 ft. lb. for most cold-mould irons. Using repeated-impact instead of the single-blow test, this iron compares still more favourably, the impact resistance so determined being usually several times as good as that of the usual irons; for example, 3,000-4,000 blows in the standard Mohr & Federhaff test above, against 300-600 blows for the ordinary irons.

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* R. T. Rolfe and J. Laing, "Cast Iron Specifications and Testing," *Foundrywork & Metallurgy*, Pitman's, Vol. VI, p. 1380, Fig. 22.

By pre-heating the mould to a suitable temperature, one can obtain an iron which is grey throughout, but which has, nevertheless, a very low silicon content. This fact has an important industrial consequence, in rendering this iron eminently suitable for use under high-temperature conditions where a material of good strength and shock resistance is required. Cast iron repeatedly heated and cooled suffers from a process of growth and gradual disintegration, which has been investigated by several workers, notably by Carpenter and Rugan,* and by Pearson,† so that the chief factors are now fairly well recognised. Within the usual range for grey cast iron, growth on repeated heating and cooling is greater, the greater the silicon content of the iron, while growth is also promoted by oxidising conditions. Some of Pearson's results are plotted in Fig. 131, showing the

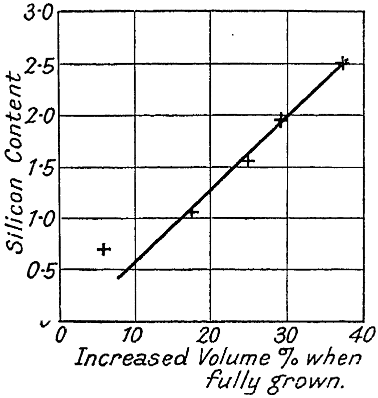

FIG. 131.—TOTAL GROWTH ON HEATING COMPARED WITH SILICON CONTENT OF CAST IRON (PEARSON)

relation between total growth and silicon content, a direct relationship being seen. According to Pearson, "irons cast by the Lanz process, in which the percentage of silicon may be made very low, show little growth, and are especially suitable for use under conditions which promote growth." This was also confirmed by Donaldson* in his work on the comparative growth of a number of samples of Lanz Perlit and of various other irons, repeatedly heated at temperatures up to 550° C. This quality has led to a number of applications of this iron—retorts for low-temperature carbonisation, firebars, ingot moulds and the like—where good heat resistance is essential. Fig. 132 shows, for example, the end and side views of four castings of channel section, two of Lanz Perlit containing 0·80 per cent. of silicon, and the other two of ordinary iron, containing 2 per cent. of silicon, all made from the same pattern, and machined to the same dimensions, being then subjected to 42 heatings at 850° C. The white lines indicate the original length and width, and the respective linear growths are 3·8 per cent. for Lanz Perlit and 9·2 per cent. for the ordinary iron, the greater distortion of which can also be seen. Although within the usual range of the grey cast irons, which contain not more than about 3·5 per cent. of silicon, the growth and deterioration of cast iron on heating varies directly with the silicon content, yet, on continuing to increase the silicon, the growth reaches a maximum at about 3 to 4 per cent. of this constituent—varying somewhat in different irons—and thereafter decreases, reaching finally a very low figure. As regards scaling and growth, these high-silicon irons are even superior to Lanz Perlit, but they are mechanically very brittle, are liable to fracture if the application of heat is too sudden—being, for example, unsuitable for ingot moulds—or if the conditions of service involve mechanical stress or shock. Where the conditions are suitable, however, these irons behave excellently at temperatures as high as 900° C.

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* Carpenter and Rugan, *Journ. I. & S. I.*, 1909, No. II, p. 29; Carpenter, *Journ. I. & S. I.*, 1911, No. I, p. 196.

† C. E. Pearson, *Journ. I. & S. I.*, *Carnegie Res. Mem.*, 1926, Vol. XV, p. 281 ("The Growth of Commercial Grey Cast Iron").

Thyssen-Emmel iron is another pearlitic iron of high strength, being superior to Lanz Perlit in this respect. While the strength of the latter usually varies between 16 and 21 tons per sq. in., according to composition, Emmel iron can be made with a tensile strength as high as 27 tons per sq. in. It has, however, a much greater silicon content, and is therefore not comparable with Perlit where resistance to heat is required in service. Again, it shows much greater variation in different parts of the casting. The process seeks to produce a very strong iron by reducing the content of carbon to a low figure, this being obtained by the use of somc 50 per cent., or more, of steel scrap in the charge, and the adjustment of the blast conditions so as to obtain a carbon content suitable for the particular casting. It is essential to use a high casting temperature. This iron should have the graphite in fine curly flakes, with a matrix of fine-grained pearlite. The material can be cast without particular difficulty, but has a somewhat high shrinkage, so that the use of heads and risers approaching in dimensions those used for steel practice are necessary. For castings of thin section, Thyssen-Emmel iron is clearly superior to Lanz Perlit, being inferior, however, for those of more massive section, or where shock or heat may be experienced in service. Typical analyses of these two irons are as follows :

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* J. W. Donaldson, "The Heat-Treatment and Growth of Cast Iron," Paper before the Lancashire Branch of the Institute of British Foundrymen, Jan. 8th, 1927, *Foundry Trade Journal*, 1927, Feb. 17th and 24th.

	Lanz Perlit Iron	Thyssen-Emmel Iron
Combined Carbon %	0·85	0·75
Graphitic Carbon %	2·25	2·00
Total Carbon %	3·10	2·75
Silicon %	0·80	2·60
Sulphur %	0·135	0·10
Phosphorus %	0·22	0·15
Manganese %	1·08	1·50
Tensile Strength, tons per sq. in.	19·4	23·00

"Inoculated" Cast Irons. In the "inoculated" cast irons, as Meehanite and Ni-Tensyl, a low-silicon basis iron, such as would normally give rise to mottled or white castings, is treated with graphitising additions in the ladle, so as to obtain a fine-grained homogeneous high-duty iron, with finely-dispersed graphite in a pearlitic matrix. The product thus resembles that obtained in the Lanz Perlit process, where, however, the necessary graphitisation is obtained by slow cooling in a pre-heated mould. In the Meehanite proprietary process, the graphitising reagent is calcium silicide, the basis iron being varied in composition as desired to meet specific requirements. Meehanite iron is thus made in a number of grades, an approximate final composition for high-strength purposes being as follows: Total carbon % 2·40–2·70; silicon % 1·10–1·50; sulphur % 0·05–0·14; phosphorus % 0·10–0·20; manganese % 0·65–1·00, such an iron giving tensile strengths of 20–25 tons per sq. in., with Brinell hardness usually between 260–300, the material, however, being readily machinable.

In the Ni-Tensyl proprietary process, the graphitising additions are finely-divided ferro-silicon and F. nickel shot, added to a basis mixture of composition approximately as follows: Total carbon % 2·5–3·0; silicon % 0·5–0·8; sulphur % 0·12 (max.); phosphorus % 0·20 (max.); manganese % 0·7–1·0. Such iron, frequently cupola-melted, contains from 50 to 90 per cent. of steel scrap, the remainder being selected ordinary scrap, Ni-Tensyl scrap or selected pig. By inoculation in the ladle, the silicon is increased to 1·25–1·75 and the nickel to 1·0–2·0 per cent., a composition with about 1·5 per cent. of each giving satisfactory results over a wide range of casting thickness. If the carbon content is kept between 2·5 and 3·0 per cent., tensile strengths of 22–30 tons per sq. in. are obtainable, with a Brinell hardness of some 280, this iron being quite machinable. Since the addition of more than 1 per cent. of nickel in the ladle cools the metal undesirably, the authors, in making such iron, melt the F. nickel shot with some No. 3 medium-phosphorus iron in a crucible, before adding it to the ladle, the only solid addition being the powdered ferro-silicon. A representative cast showed: Tapped from cupola, 9½ cwt.; melted in crucible, 72 lb. (including 16 lb. of F. nickel shot); added solid, 14 lb. of 50 per cent. ferro-silicon, finely powdered. Here the silicon content was: Calculated 1·72; actual 1·59 per cent., the nickel content being: Calculated 1·28;

actual 1·22 per cent., the tensile strength on an M test bar (1·2 in. in diam.) being 22 tons per sq. in., with a Brinell hardness of 277. In both these irons, when of maximum strength, with low total-carbon content and short freezing range, runners and risers must be of ample proportions. There is a tendency for Ni-Tensyl to tear during solidification, so rod-feeding is not desirable, self-feeding risers being used instead.

Superheating for Graphite Refinement. It has long been known that superheating grey cast iron to about 1500° C. causes a fine graphite structure and improved strength,* an effect at first attributed to the solution, in superheating, of graphite particles otherwise serving as nuclei. Recent work,† however, has shown that even coarse graphite dissolves so rapidly in molten iron that this explanation is impossible. Further, Norbury and Morgan,‡ who made melts from thin and completely white sections of a casting, and alternatively from thick sections, containing coarse graphite, from the same casting, found no differences, even on rapid melting at low temperatures, in the fractures of the resulting ingots.

Effect of Gases and Non-Metallic Inclusions on Graphite Size. Alternative explanations for the effect of superheating depend on the presence of gases or non-metallic inclusions in the molten metal. In small ¼-lb. crucible melts, made by the same experimenters, dissolving 0·1 to 0·2 per cent. of titanium, and bubbling carbon dioxide through the melt, completely refined the graphite of all hypo-eutectic grey cast irons. A similar use of hydrogen coarsened the graphite completely. The graphite fineness in various pig-irons and ferro-alloys re-melted under oxidising conditions was also determined by the titanium content. Norbury and Morgan suggest that titanium-carbon dioxide treatment produces titanate inclusions which are externally liquid when the graphite separates, and so do not inoculate it, and super-cooling occurs, resulting in fine graphite. Additions of silicon, calcium silicide and aluminium produce solid and therefore inoculating inclusions—as silicates, calcium carbide and alumina—coarse graphite resulting. Hydrogen is assumed to reduce iron oxide from titanate inclusions, increasing their content of silica and titanium oxide, and raising the freezing point. Cupola-melted metal was found to be more difficult to refine than that crucible-melted, owing to the combination of the dissolved titanium with inclusions already present in the metal, and its consequent removal from the melt. Titaniferous charges giving fine graphite when crucible-melted gave coarse graphite when cupola-melted, due, as conjectured, to the effect of reducing conditions in certain parts of the cupola, with a result resembling that of hydrogen, above.

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* E. Piwowarsky, *Trans. Amer. Foundrymen's Assn.*, 1926, Vol. 34, 914–985; H. Hanemann, *Stahl & Eisen*, 1927, Vol. 47, 693; P. Bardenheuer and K. L. Zeyen, *Giesserei*, Vol. 15, 354, 385.

† E. Piwowarsky, "The Rate of Solution of Graphite in Molten Iron," *Archiv. für das Eisenhüttenwesen*, 1933–34, Vol. 7, 431–2; *Giesserei*, 1935, Vol. 22, June 7th, 274–7.

‡ A. L. Norbury and E. Morgan, "The Effect of Non-Metallic Inclusions on the Graphite Size of Grey Cast Iron," *Journ. Iron & Steel Inst.*, No. 2, 1936, Vol. 134, 327 P.

In the discussion on this paper, Desch said that super-saturation could not be relieved unless the introduced nuclei had a crystal structure similar to that of the solid phase about to be precipitated. It was difficult to see how a solid silicate particle could form a nucleus for graphite precipitation. Also, although graphite dissolved rapidly above the melting point of iron, yet there was evidence of the existence, in molten iron, of molecular groupings corresponding with iron, iron carbide and graphite, groupings which were gradually destroyed on heating, but survived for a time. In cooling—although not having reached the stage of crystallising out of solution—they might yet furnish the requisite nuclei. Colbeck and Comstock doubted whether titanium occurred in cast iron as a titanate, suggesting titanium cyano-nitride or carbide as more likely forms, such inclusions being solid before the iron had solidified completely, thus fulfilling the function of nuclei. Comstock advanced an alternative theory, that the presence and not the absence of nuclei caused refined graphite. Refinement would thus be analogous to that of aluminium to produce nuclei of alumina in steel, of titanium giving rise to those of titanium cyano-nitride in austenitic stainless steels; and of titanium to produce inclusions of solid $TiAl_3$ in aluminium alloys—

all these inclusions promoting fine crystals, either by interference with the grain growth, or by causing more crystals to grow in a given volume, when none could grow so large. So, in cast iron, if the primary austenite grains were finer, because these nuclei were present, the graphite separating later within the grains would also be finer. The action of the respective gases could similarly be explained, as reinforcing the observed effects, either by the formation of additional nuclei of iron oxide or silica in the iron when oxidised, or by a reduction in the number of nuclei when reduced.

The Effect of the "Silicate Cloud" on Graphite Refinement. There is other evidence, however, that it is the absence and not the presence of non-metallic inclusions which promotes fine graphite. Thus, Keil and his collaborators* found that the mode of solidification of cast iron was chiefly dependent on sub-microscopic particles of iron silicate, which they termed "silicate cloud" (*Silikattrübe*), and there was a direct relationship between the amount of this constituent and the graphite size, irons low in silicate cloud showing fine graphite. Mitsche† also notes the finer graphite structure when the clouds are rare or absent.

Much further work is necessary before these phenomena can be fully explained. Possibly, the effect of inclusions may vary greatly with their size. If very small, then fine graphite may result, as advanced by Comstock. If large, coarse graphite may be produced, according to the usual theory, for which there seems more support. In view of its practical importance, the successful application of methods of graphite refinement to cupola-melted irons—where some progress has already been made—will be awaited with considerable interest.

Shrinkage in Cast Iron. This occurs in three stages, in the molten metal before solidifying (liquid shrinkage); in solidifying (solidification shrinkage); and in the solid metal

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* O. von Keil and others, "The Influence of Non-Metallic Nuclei on the Formation of Graphite in Cast Iron," *Archiv. für das Eisenhüttenwesen*, 1934, Vol. 7, Apr., 579–584.

† R. Mitsche, "Very Finely-Divided Non-Metallic Inclusions, and the Action of Kindred and Foreign Nuclei," *Iron & Steel Inst. Carn. Schol. Mem.*, Vol. 25, 1936, 41.

(solid shrinkage, *i.e.*, the pattern-maker's contraction allowance). In nearly all cases, any alloy just after solidification has a greater density and a lesser volume than in the liquid state. Pure iron at 1537° C., just above its melting point, has a density of 6·94, as compared with 7·10 at 1535° C., when just solid, corresponding to a solidification shrinkage of about 2·3 per cent. Molten cast iron has a density of 6·65, varying little from this figure whether the solid iron is ultimately grey, white or intermediate. The shrinkage during solidification can now be calculated by reference to the density of the solid metal in the cold, as given in the first column of the following table :

Description of Iron	Sp. Gr. in the Cold	Sp. Gr. at 1130° C. (solid)
Coarse-grained grey pig-iron ..	6·80	—
Coarse-grained grey cast iron ..	7·00	—
Fine-grained cast iron	7·20	—
Mottled pig-iron	7·64	—
White pig-iron	7·69	7·33
White charcoal high-phosphorus cast iron	7·80	7·43
Average grey iron	7·10	—
Average white iron	7·50	7·15

We may assume that 1130° C. is an average figure for the solidifying point of ordinary foundry iron, disregarding the phosphide constituent, and, since the density of pure iron shows an approximately linear relation with temperature, that there is a similar relative expansion in cast iron. The density at 1130° C. (solid) is thus about 95·3 per cent. of that in the cold, from which the amended density figures in the second column of the table can be calculated. We have seen that all irons solidify white, whether they are fully grey, white or intermediate when cold. With a density of 6·65 when molten, and a density which varies between 7·33 and 7·15 when just solid, we have solidification shrinkages varying from 7 to 11 per cent., giving an average of 9 per cent., a figure which is arrived at independently by Moldenke. There is a partial compensation for this by graphitisation.

Graphitisation in Cast Iron. It is a simple matter to calculate that 100 volumes of Fe_3C become 113 volumes of iron plus graphite. But Fe_3C contains 6·67 per cent. of carbon. Therefore, every 1 per cent. of carbon converted from the combined to the free state corresponds to an expansion of 1·95 per cent. In a foundry pig-iron containing 3·6 per cent. of carbon, assuming that it finally contains 3·0 per cent. of graphite, this must be equivalent to an expansion of 3 × 1·95, or 5·85 per cent., as compared with a solidification shrinkage of about 9 per cent. Graphitisation must thus tend to reduce shrinkage, because the casting does not solidify all at once, but in a series of stages, and therefore

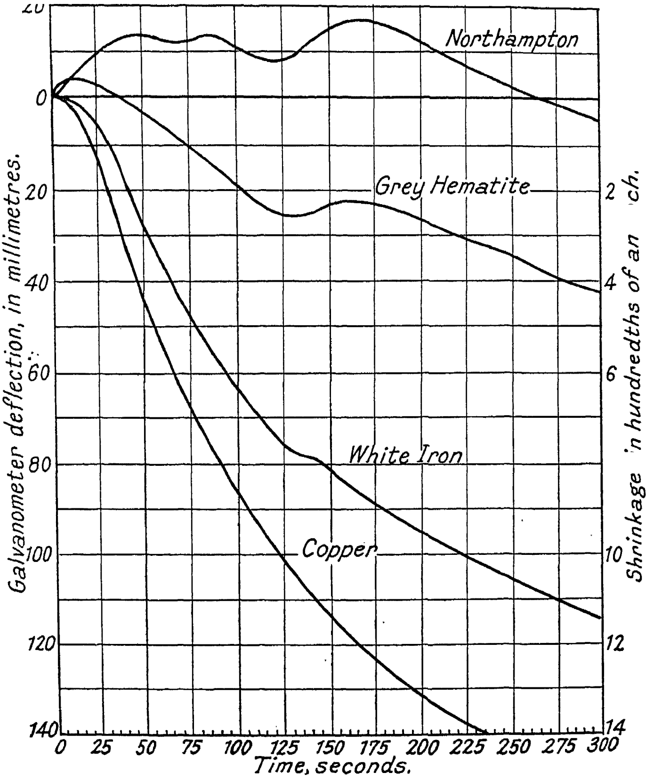

FIG. 133.—TYPES OF CONTRACTION-CURVES FOR DIFFERENT IRONS IN COOLING (TURNER)

graphitisation in the metal which has solidified earlier must obviously leave a smaller volume to be occupied by the still liquid metal.

The Changes after Solidification. The results of Turner's experiments (1906) are shown graphically in Figs. 133 and 134. Fig. 133 shows the regular contraction of copper, and the momentary expansions taking place at different temperatures in the cooling of three typical cast irons. Fig. 134 is of a fourth iron, where the cooling curve gives the actual temperatures of the change points. There are generally three expansions, varying slightly in position with composition, the middle one, caused by the separation of the phosphide eutectic, being naturally absent in phosphorus-free irons.

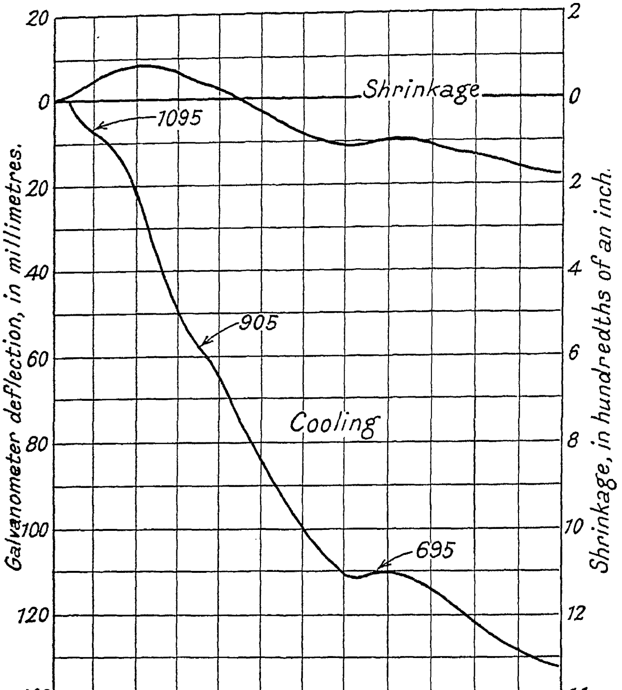

FIG. 134.—CONTRACTION CURVE OF FOUNDRY IRON COMPARED WITH COOLING CURVE (TURNER)

The temperatures at which the various arrests in contraction were found were as follows :

	Iron containing			
	Carbon only	Carbon and Silicon	Carbon, Silicon and Phosphorus	
			No. 1	No. 2
First arrest	Almost absent	at 1135° C.	at 1060° C.	at 1095° C.
Second arrest	Absent	Absent	at 900° C.	at 905° C.
Third arrest	at 665° C.	at 695° C.	at 730° C.	at 695° C.

The respective compositions were as follows :

	White Iron	Grey Hematite	Northamptonshire Iron	Good Close-grained Foundry Iron
Combined carbon %	2·73	0·86	0·15	0·79
Graphitic carbon %	—	2·53	2·60	2·73
Total carbon % ..	2·73	3·39	2·75	3·52
Silicon %	0·01	3·47	3·98	1·41
Sulphur %	traces	0·03	0·03	0·07
Phosphorus % ..	0·01	0·04	1·25	0·96
Manganese % ..	traces	0·55	0·50	0·43

The first arrest represents the liberation of primary graphite, which occurs at temperatures which are lower as the phosphorus increases. The last arrest represents the liberation of secondary or temper graphite, and occurs at temperatures which are higher as the silicon increases. We have already seen that all the graphite is not deposited soon after solidification, but that which is deposited at the pearlite transformation point can have little or no tendency to diminish shrinkage, because, at this temperature, the whole of the casting has long been solid, and any shrinkage cavities have been already produced.

Shrinkage Effects in the Production of Castings. If the production of shrinkage cavities can be minimised by ensuring the separation of a maximum quantity of graphite, then sounder castings must be produced by using high-silicon irons cast hot. Low-silicon irons cast cold must show less graphitisation and more shrinkage. On the other hand, there is, with many alloys, iron included, a temperature range for casting, within which the best results—for example, the highest strength—may be obtained. Again, the separation of too much graphite, especially in the form of large flakes, causes the metal to be of open grain and mechanically weaker, although hydraulically more sound. It might perhaps be supposed that a hard close-grained metal would produce sounder castings, but this metal has a greater shrinkage and must therefore be more liable, when the thickness varies, to leak under the water test. Open-grained castings show less local porosity, and leakage seldom occurs through metal which is open-grained, while "hard close-grained metal" frequently shows porous regions, through which leakage readily occurs.

Testing of Cast Iron. The authors have discussed *in extenso* elsewhere* the specifications and testing of cast iron and this should be referred to. It is assumed here that foundrymen are familiar with the requirements of B.S.I Specification No. 321 for Grey Iron Castings, and with those of the British Admiralty. It should be of value, however, to consider the various transverse tests which are commonly demanded, the relation between the transverse and tensile figures for different irons, and the quality necessary to obtain the results required.

The Transverse Strength of Cast Iron. B.S.I Specification No. 321 requires transverse bars of 0·875, 1·2 or 2·2 in. in diameter—corresponding to the main cross-sectional thickness of the casting—which are broken, as cast, on distances of 12 in., 18 in. and 18 in. respectively, with minima for the two different grades, as detailed in the table below. Other transverse tests commonly used are: (*a*) a machined test bar, 1 in. square, broken on 12-in. centres—minimum load 2000 lb., and (*b*) a bar 2 in. by 1 in., as cast, broken on 36-in. centres—minimum load of 30 cwt., and minimum deflection 0·3 in. The results from these various tests can be related by determining in each case the Modulus of Transverse Rupture, f, when, if the span is L in., the breaking load W tons, and the modulus of section Z, then:

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* See *Foundrywork and Metallurgy* (Pitman's), "Cast Iron Specifications and Testing," Vol. VI, p. 1327.

$$f = \frac{WL}{4Z} \text{ tons per sq. in.}$$

In the case of the various test bars referred to, the requirements are thus as follows :

TRANSVERSE LOAD REQUIREMENTS

Test Bar	Dimensions, in.	Distance between supports, in.	Grade A		Grade C	
			Min. load, lb.	Modulus, tons/in.²	Min. load, lb.	Modulus, tons/in.²
B.S.I. 321–S	0·875 dia.	12	1,185	24·1	960	19·6
Do. –M	1·2 dia.	18	1,950	23·1	1,600	18·9
Do. –L	2·2 dia.	18	10,000	19·2	8,950	17·2
			Minimum load, lb.		Modulus, tons/in.²	
—	1 in. sq.	12	2,000		16·07	
—	2×1 in.	36	3,360		20·25	

As a typical series of results from practice, we may take those of 395 consecutive tests on a cylinder iron of the composition stated, for Admiralty turbine casings and gear cases, where a minimum tensile strength of 13 tons per sq. in., and a minimum transverse load of 1130 lb. on S bars were required. B.S.I Specification No. 321, Grade A, would require 12 tons and 1185 lb. on the transverse bar.

COMPOSITION OF "CYLINDER MIXTURE"

Glenhill No. 3	10%
Hematite (Si 1·5%) ..	15%
Spiegeleisen (Mn 17%)	2·5%
Goldendale (Si 2%) ..	20%
Steel Pig (50 : 50 steel and Glen. 3) ..	27·5%
Returns	25%
Total	100%

Carbon, combined %	0·80
Carbon, graphitic %	2·50
Carbon, total % ..	3·30
Silicon %	1·15
Sulphur % ..	0·12
Phosphorus % ..	0·35
Manganese % ..	0·80

Here the average figures for the whole of the tests were 15·50 tons per sq. in. tensile strength, and 1617 lb. for the transverse test on the S bars. The results have been separated into a series of classes, based on the tensile test, so as to enable the results of this test and those of the transverse test to be compared with each other. All the results are on S bars cast on, the two broken halves of the transverse bar being machined into tensile bars, so that there can be no doubt as to the identity in quality of the material used for the respective tests. Those average figures against which a note of interrogation has been placed are doubtful, because of the small number of tests.

TENSILE AND TRANSVERSE TESTS ON ROUND BARS

Group of Tensile Tests	Number of Tests in Group	Tensile Test Figures, tons per sq. in.		Transverse Test Figures, lb. to fracture S bars		
		Range	Average	Average	Highest	Lowest
Group 1	13	12·5—13·5	13·06	1617	2004	1250
„ 2	79	13·5—14·5	14·12	1588	1913	1254
„ 3	105	14·5—15·5	15·01	1592	2074	1198
„ 4	128	15·5—16·5	15·94	1640	2229	1330
„ 5	44	16·5—17·5	16·91	1628	2132	1366
„ 6	17	17·5—18·5	17·97	1662	2016	1382
„ 7	4	18·5—19·5	18·91 (?)	1651 (?)	1859	1362
„ 8	5	19·5—20·5	19·68 (?)	1803 (?)	2020	1718

It will be noted that the increase of transverse with tensile strength is only slight, and much more erratic than one would have expected. This round test bar appears to be definitely inferior in this respect to the 1-in. square bar, which it has very largely superseded. This is shown by a set of 284 consecutive results on a very similar iron, from the 1-in. square bar, taken quite at random :

TENSILE AND TRANSVERSE TESTS (1-in. square bar)

Group of Tensile Tests	Number of Tests in Group	Tensile Test Figures, tons per sq. in.		Transverse Test Figures, cwt. to fracture on 12-in. span		
		Range	Average	Average	Highest	Lowest
Group 1	2	8·5— 9·5	9·25 (?)	25·4 (?)	25·6	25·2
„ 2	19	9·5—10·5	10·06	27·31	34·8	19·8
„ 3	21	10·5—11·5	11·15	28·35	32·2	25·2
„ 4	48	11·5—12·5	12·03	29·31	37·0	23·2
„ 5	64	12·5—13·5	13·05	29·97	41·4	22·6
„ 6	44	13·5—14·5	13·98	31·02	41·6	24·4
„ 7	45	14·5—15·5	14·99	31·70	43·0	25·2
„ 8	27	15·5—16·5	15·92	33·35	43·2	26·2
„ 9	12	16·5—17·5	16·88	33·87	39·2	26·6
„ 10	2	17·5—18·5	17·60 (?)	35·2 (?)	37·2	33·2

Here there is a definite relationship between the transverse and tensile test results, which are plotted in Fig. 135. The consistency of the relation between the results of the 1-in. sq. transverse bar and the tensile test is once more shown by the results of a series of consecutive tests on Lanz Perlit iron. These, which were chosen quite at random, are detailed in the same manner as before in the table below, and are plotted in Fig. 136.

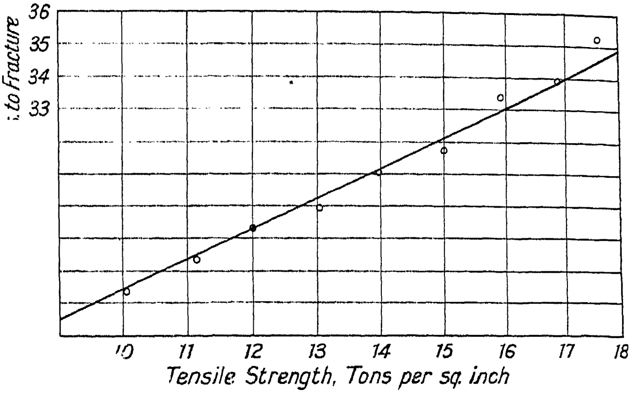


FIG. 135.—THE RELATION BETWEEN TRANSVERSE AND TENSILE STRENGTH IN CAST IRON—TRANSVERSE BAR 1-IN SQ. ON 12-IN. CENTRES

TENSILE AND TRANSVERSE TESTS (1-in. sq. bar) ON LANZ PERLIT IRON

Group of Tests	Number of Tests in Group	Tensile Test Figures, tons per sq. in.		Transverse Test Figures, cwt. to fracture		
		Range	Average	Average	Highest	Lowest
Group 1	21	12·5—13·5	13·05	31·81	37·2	27·2
,, 2	45	13·5—14·5	14·05	32·84	40·2	26·8
,, 3	65	14·5—15·5	15·02	33·80	42·8	27·2
,, 4	66	15·5—16·5	15·90	34·92	43·2	27·4
,, 5	71	16·5—17·5	16·97	35·93	45·6	27·6
,, 6	57	17·5—18·5	17·90	36·96	46·0	30·8
,, 7	13	18·5—19·5	18·90	37·65	45·2	31·2
,, 8	6	19·5—20·5	19·93	40·8 (?)	46·2	37·2
,, 9	2	Over 20·5	20·72	38·2 (?)	40·2	36·2

It should be noted that these test bars represent castings of comparatively thin section, so that the silicon content is higher and the strength is correspondingly lower than in heavier castings in this iron. Comparing with the table on p. 221, of similar results from a cylinder iron, it will be seen that Lanz Perlit has, for any given tensile strength, a transverse strength which is about 2 cwt. greater. The present results confirm the straight-line relationship between the tensile test and the transverse test on the 1-in. square bar, the superiority of which over the round bar is thus further demonstrated. The supersession of the square bar by the round bars of the British Standard Specification appears thus a little unfortunate. The transverse test results that may reasonably be expected, for any given tensile strength, from the 1-in. square bar, are obvious, and it is manifest that the 2000 lb. minimum for this test is much too low.

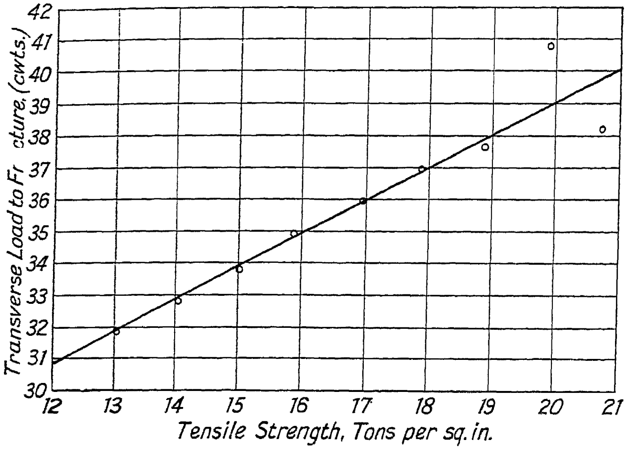


Fig. 136.—The Relation between Transverse and Tensile Strength in Lanz Perlit Iron—Transverse Bar 1-in. square on 12-in. centres

Hardness Tests. As approximate Brinell figures for different grades of cast iron, white iron may be taken as of 450 Brinell, mottled iron (*i.e.*, half white and half grey) as 325, and average grey iron as 200, although it may of course be considerably softer. A minimum figure specified in the authors' practice for parts for pumps dealing with abrasive materials is 280, such castings being naturally much more difficult to machine. For liners for Diesel engines, minima of 200 and 220, respectively, have been specified.

Pig Irons. For the manufacture of castings for diverse purposes, there are available to the founder a large number of pig irons of varying quality and price. The problem of the choice and the combinations to be used for castings for any particular service is a question of cost, and of the composition and mechanical tests stipulated for the finished castings, which must at the same time be suitable for their duty. One generally uses a mixture of pig irons and scrap, although the use of one iron, if it is of the right composition and quality, should be quite as satisfactory as any mixture of irons. The use of a mixture has the advantage that periodical variations in consignments has less effect.

Where, however, as for all important castings, one is mixing by analysis, variations are less important, but the use of several pig irons enables one more readily to calculate the compositions for specific purposes. By reason of the varying distances of the respective foundries from the pig-iron districts, there is a great difference in the prices of the same iron in different parts of the country. It is thus inadvisable to stipulate which brands should be used. It is naturally advantageous to employ irons made near at hand, but it is frequently essential to use at least some proportion of that from a distance. In general, high duty castings necessitate the use of irons low in carbon and phosphorus, and cold or warm blast irons are more suitable. For ordinary work, hot blast irons can be utilised to a considerably greater extent, while a higher proportion of phosphorus is much less objectionable. The effect of this constituent has already been discussed, but should now be considered further. The quantity of phosphorus in pig iron depends almost exclusively upon that in the ores from which it is made, and, unlike carbon and silicon, is not a variable depending mainly upon the mode of operation of the blast furnace. If the same ores are being used, the phosphorus content of the pig iron remains therefore fairly consistent. As phosphorus has a considerable influence, both in the casting operation and on the mechanical quality of the castings produced, it affords a convenient means of classifying the pig irons available to the founder. Apart from the special cold blast and the refined pig irons, these can approximately be divided into three classes—the low-phosphorus (hematite irons), the medium-phosphorus and the high-phosphorus pig irons. The following table (p. 226) gives the approximate compositions of typical foundry pig irons on the British market.

Foundry Mixtures. The mixtures commonly used for general engineering purposes are made largely from the second group, with the addition of cast-iron scrap. Irons of the third group are rather weak and brittle, but they are exceptionally fluid and constitute the basis of mixtures used in the light castings trade. Castings for special duties are made usually from mixtures of irons of the first and fourth groups, frequently with additions from the second group and of mild steel scrap. There are of course many exceptions to these "rules," and the geographical position of a particular foundry may make it necessary, for economic reasons, to depart somewhat from the lines laid down. Care must be exercised, however, when such departures are made. Thus, mixtures containing a high proportion of hematite irons are never really satisfactory for castings which are to be highly machined, for they lack the necessary fluidity or "life" to enable entrained gas or air bubbles to escape from the metal. At the other extreme, the high-phosphorus irons are particularly fluid, but they are very susceptible to sponginess in bosses, at the roots of ribs or flanges, or elsewhere where the mass is such as to lead to delayed solidification.

In calculating the composition of the metal, it is necessary to allow for the various changes that are found in melting in the cupola, the effect on the proportion of each constituent charged varying with the proportion of steel in the charge, and the cupola conditions, so that considerable differences in these figures may be found in practice. The following figures afford some general indication of these alterations.

Alteration in composition brought about in cupola melting.	For low-silicon mixtures, containing 20–30 per cent. steel.	For higher silicon mixtures, containing only pig iron and scrap
The content of silicon is reduced ..	25%	16%
The content of sulphur is increased ..	50%	25%
The content of phosphorus is increased	5–10%	5–10%
The content of manganese is reduced	30%	10–20%

BRITISH FOUNDRY PIG IRONS

	Carbon, comb., %	Carbon, graph., %	Carbon, total %	Silicon %	Sulphur %	Phosphorus %	Manganese %
Hematite Pig Irons :—							
Barrow No. 1	0·95	2·95	3·90	2·5	0·030	0·035	0·75–1·5
Consett No. 1	0·20	3·80	4·00	2·0–3·0	0·04 (max.)	0·05–0·06	0·8–1·3
Clyde Ordinary	0·35	3·75	4·10	2·0–2·5	0·05 (max.)	0·05 (max.)	1·0–1·5
G.K.B. No. 1	—	—	3·8–4·2	2·25–2·75	0·040	0·065	0·8–1·2
Scotch Irons and English Medium-Phosphorus Irons :—							
Eglinton No. 4	0·60	2·90	3·50	1·75	0·085	0·60	1·20
Gartsherrie No. 4	0·55	2·95	3·50	1·5–2·0	0·080	0·50	1·00
G. & R.T. Spec. No. 4	—	—	3·0–3·5	1·0–1·75	0·04–0·065	0·30–0·50	0·50–0·80
G.K.B. Grade H.P.	—	—	3·3–3·7	2·0–4·0	0·05	0·50–0·60	0·50–0·80
Cleveland and Northamptonshire High-Phosphorus Irons :—							
Cleveland No. 4 Foundry ..	0·25	3·40	3·65	2·0–2·5	0·05–0·08	1·50	0·5–0·7
G.W.L. No. 4	0·45	3·05	3·50	1·5–2·0 2·0–2·5	0·03–0·05	1·60	0·45–0·55
Cransley No. 4	0·35	2·75	3·10	2·5	0·025	1·60	0·35
Kettering No. 4	0·25	2·90	3·20	2·75	0·02	1·55	0·35
Semi-Cold Blast, Cold Blast, and Refined Pig Irons :—							
Goldendale Cylinder	0·8	2·2	3·0	1·0–2·5	0·06	0·35	1·4
L.N. F'ces DUD No. 4 ..	0·55	2·60	3·15	1·10	0·075	0·45	0·70
Stanton Dale Grade D ..	—	—	2·6–2·8	2·4–2·6	0·05	0·50	0·8–1·5
Warner's CBR No. 4 ..	—	—	3·25	1·25	0·04	0·10	0·50

It is of course advisable to determine the approximate variation caused by melting in one's own cupolas. An iron suitable for cylinders and liners for steam engines, Diesel engines, and gas engines ; piston rings, etc., is as follows :

Silicon % (nom.)	1·2–1·4
Phosphorus % (nom.)	0·3–0·5
Manganese % (nom.)	0·8–1·2

This is in each case the percentage charged to the cupola, the approximate final figures being calculable by reference to the figures quoted above. Such an iron can be made by the use of 25-40 per cent. of returns from the previous casts and 20-30 per cent. of steel, the remainder being irons of No. 3 and No. 4 grades. If the proportion of manganese is too low, it is brought up by the use of spiegeleisen, ferro-manganese or manganese briquettes. When particularly high strength is required, a proportion, 20 per cent., for example, of iron made by the use of a cold or low-temperature blast should be employed.

An iron suitable for pipes, bedplates, condenser bodies, pump casings, and general castings from ½ to 1½ in. in thickness, can be obtained by calculating on charge figures as follows :

Silicon % (nom.)	2·0–2·75
Phosphorus % (nom.)	0·6–1·0
Manganese % (nom.)	0·5–0·7

It will be useful to show a method of calculating the mixture for an iron to contain 2·0 per cent. of silicon, 1·0 per cent. of phosphorus and 0·6 per cent. of manganese, with a maximum of 0·10 per cent. of sulphur. As a hypothetical case, the materials available are as given in the table below, and it is desired to use 50 per cent. of returns in the mixture.

	Silicon %	Sulphur %	Phosphorus %	Manganese %
Stanton :				
No. 1 Foundry ..	3·50	0·015	1·40	0·45
„ 3 „ ..	2·91	0·025	1·40	0·45
Dalzell :				
No. 1	3·35	0·03	0·30	1·10
„ 4	1·50	0·035	0·30	1·10
Returns	2·00	0·10 (max.)	1·00	0·60

Allowing for alterations in the cupola, the mixture charged must contain 2·66% silicon, 0·91% phosphorus, 0·86% manganese, and sulphur not exceeding about 0·066%. Since phosphorus usually shows little variation in the different numbers of any one brand, this figure should be calculated first. Since the 5 cwt. of returns contain 1% of phosphorus, the average in the remainder must be 0·8 per cent. The pigs available show 0·3% in the lowest and 1·1% more than this in the other, the 5 cwt. additional charge requiring to be 0·5 per cent. above the lowest. Then:

$$\text{Cwts. of } 1{\cdot}4\% \text{ Phos. pig required} \times 1{\cdot}1 = 5 \times 0{\cdot}5$$

$$\text{Cwts. of } 1{\cdot}4\% \text{ Phos. pig required} = \frac{5 \times 0{\cdot}5}{1{\cdot}1} = 2{\cdot}27 \text{ cwts.}$$

$$\therefore \text{cwts. of Dalzell pig required} = 5 - 2{\cdot}27 = 2{\cdot}73 \text{ cwts.*}$$

The mixture consists as follows:

5 cwts. Scrap @ 1% P. = 5
2·73 ,, Dalzell @ 0·3% P. = 0·82
2·27 ,, Stanton @ 1·4% P. = 3·18

9·00

It is now required to calculate the silicon, which we may do by assuming that 2·27 cwts. of Stanton No. 1 will be used, and 2·73 cwts. of Dalzell Nos. 3 and 4 together, the exact proportions of these to be calculated as shown below.

The 10 cwts. are required to contain 2·66% = 26·6 cwt. %

We have already:

5 cwts. Returns @ 2·0% = 10·0 cwts. %
2·27 cwts. Stanton No. 1 @ 3·5% = 7·945 cwts. %

Total 17·945 cwts. %

---

* It may be easier for some to calculate by means of simultaneous equations. Suppose it is *a* cwts. of the Dalzell and *b* cwts. of the Stanton which will give the percentage required. Then:

$$\begin{aligned} &(1) \quad a + b = 5 \\ &(2) \quad 0{\cdot}3\,a + 1{\cdot}4\,b = 5 \times 0{\cdot}8\% = 4{\cdot}0 \\ &(3) \quad 0{\cdot}3\,a + 0{\cdot}3\,b = 5 \times 0{\cdot}3\% = 1{\cdot}5 \end{aligned}$$

Then, subtracting (3) from (2),

$$1{\cdot}1\,b = 4 - 1{\cdot}5 = 2{\cdot}5$$

$$\text{or } b = \frac{2{\cdot}5}{1{\cdot}1}, \text{ as before}$$

∴ the mixture is still low in silicon by 26·6 — 17·945 or 8·655 cwts. %, which is to be supplied by 2·73 cwts. of the two grades of Dalzell pig.

$$\text{The average silicon required in remainder} = \frac{8\cdot655}{2\cdot73} = 3\cdot1703\%$$

The silicon in Dalzell No. 4 pig is 1·5%.
The silicon in Dalzell No. 1 pig is 1·85% above this.
The 2·73 cwts. required will be 1·6703% above the lowest.
∴ Cwts. of No. 1 @ 3·35% × 1·85 = 2·7 × 1·6703 = 4·5671

$$\therefore \text{Cwts. of No. 1 Dalzell} = \frac{4\cdot5671}{1\cdot85} = 2\cdot47$$

∴ Cwts. of No. 4 Dalzell = 2·73 — 2·47 = 0·26*

The mixture is thus made up as follows :

5	cwts.	Scrap @ 2% Si	=	10·000
2·27	,,	Stanton No. 1 @ 3·50% Si	=	7·945
2·47	,,	Dalzell No. 1 @ 3·35% Si	=	8·274
0·26	,,	Dalzell No. 4 @ 1·50% Si	=	0·390
				26·609

It will be found on checking through that this mixture only contains 0·70 per cent. of manganese, instead of 0·86 per cent. It can be made up if necessary by adding the appropriate amount of 80 per cent. ferro-manganese, with little prejudice to the proportions of the other constituents.

For the general guidance of the foundryman, it will be useful to add a series of typical mixtures for different classes of work, with the compositions of representative casts, and the mechanical test results obtained. For each mixture, four each of the British Standard S, M and L bars were cast in dry-sand, the transverse tests being made on the bars as cast, applying correction factors for variation in diameter from the standard dimensions. The tensile test pieces were machined from the broken halves of the transverse bars. The diameters of the tensile test pieces were respectively as follows—for the S bars, 0·564 in; for the M and L bars, 0·798 in. In the case of the L bar, 2·2 in. in diameter, the test pieces were machined, alternatively, concentrically and eccentrically, the latter, being nearer to the surface of the bar, naturally giving higher results, generally of the order of some 1½ tons, as shown. The variation of carbon distribution between combined and graphitic carbon in the different sizes of bar is also recorded, showing the progressive increase in the content of graphite and decrease in that of combined carbon as the size of the bar increases and the rate of cooling is slower. In one instance, that of the Flywheel Mixture, typical micrographs have been recorded in Fig. 137, these being in all cases from the centre of the bar. These show the graphite (× 50 diam.) and the general structure (× 1500 diam.), respectively, both the graphite and also the pearlite grain size becoming progressively coarser as the size of the bar increases, the strength falling off in a corresponding manner, as will be noted. The results of five mixtures in all are detailed below :

---

* Let a cwts. of No. 1, and b cwts. of No. 4 be those required.

(1) $a + b = 2\cdot73$

(2) $3\cdot35a + 1\cdot50b = 8\cdot66$

(3) $3\cdot35a + 3\cdot35b = 2\cdot73 \times 3\cdot35 = 9\cdot14$

Then, subtracting (2) from (3)

$1\cdot85b = 0\cdot48$

$\therefore\ b = \frac{0\cdot48}{1\cdot85} = 0\cdot26$

$a = 2\cdot73 - 0\cdot26 = 2\cdot47$

C. I. Liner Mixture (Silicon % 0·8–1·0)—used for Diesel engine and similar massive cylinder liners (suitable for wear-resisting castings).

Mixture			*Typical Composition*	
1	cwt.	Carnforth No. 4 equiv. (Si % 1·50)		
3	,,	Glenhill No. 4 (Si % 1·50)	Tot. Carbon % ..	3·42
8	,,	Steel Pig (Si % 1·20)	Silicon %	0·76
1	,,	Spiegel (Si % 0·30)	Sulphur % ..	0·10
1	,,	Steel (Si % 0·12)	Phosphorus % ..	0·30
6	,,	Liner Returns (Si % 0·80)	Manganese % ..	1·06
20	cwt.			

Silicon % (calculated) = 1·04 less ⅙th loss in melting = 0·87 (nominal).

MECHANICAL TEST RESULTS

B.S.I. Bar .. .. Trans. span, in. ..	S (7/8 in. diam.) 12		M (1·2 in. diam.) 18		L (2·2 in. diam.) 18	
Carbon :—						
Combined % ..	—		1·26		0·85	
Graphitic % ..	—		2·16		2·57	
Fractures of bars ..	White, slightly mottled		60% White : 40% Grey		Fully grey	
Transverse :—	Lb. to break	Defn., in.	Lb. to break	Defn., in.	Lb. to break	Defn., in.
(*a*)	1710	3/32	3091	3/16	16,060	3/16
(*b*)	1661	5/32	2770	5/32	16,560	13/64
(*c*)	1484	3/32	2867	5/32	15,500	13/64
(*d*)	1598	5/32	2644	1/8	16,510	13/64
Average	1613	1/8	2843	5/32	16,157	13/64
Tensile T. □″ ..					Ecc.	Con.
(*a*)	(Too hard to turn)		14·80		14·20	13·54
(*b*)			15·00		13·38	13·72
(*c*)			15·30		13·32	13·94
(*d*)			15·12		13·78	13·62
	?		15·06		13·67	13·70
Brinell :—						
Surface	511		477		217	
Centre	511		269		207	

C. I. Cylinder Mixture (Silicon % 1·0 – 1·3)—used for turbine cylinders, turbine gear casings, steam engine cylinders, armature hubs, etc. (suitable for castings which must be hydraulically tight and which may have to resist moderate temperatures in service).

Mixture		*Typical Composition*	
3 cwt.	Carnforth No. 4 equiv. (Si % 1·50)		
3 ,,	Glenhill No. 3 (Si % 3·00)	Tot. Carbon % ..	3·51
3 ,,	Glenhill No. 4 (Si % 1·50)	Silicon %	1·05
5½ ,,	Steel Pig (Si % 1·20)	Sulphur % ..	0·112
5 ,,	Cyl. Returns (Si % 1·20)	Phosphorus % ..	0·33
½ ,,	Spiegel (Si % 0·30)	Manganese % ..	0·89
20 cwt.			

Silicon % (calculated) = 1·53 less ⅙th loss in melting = 1·27% (nominal).

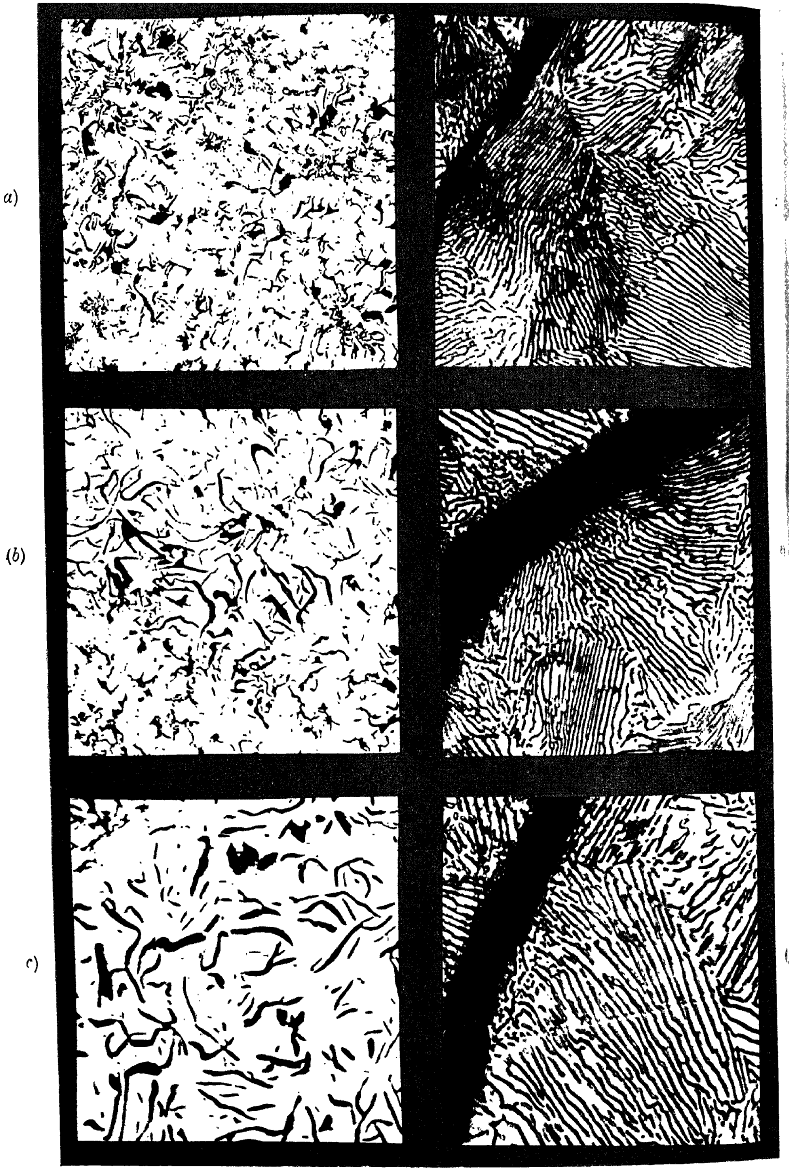
MECHANICAL TEST RESULTS

B.S.I. Bar .. .. Trans. span, in.	S (7/8 in. diam.) 12		M (1·2 in. diam.) 18		L (2·2 in. diam.) 18	
Carbon :—						
Combined % ..	0·95		0·80		0·66	
Graphitic % ..	2·56		2·71		2·85	
Transverse :—	Lb. to break	Defn., in.	Lb. to break	Defn., in.	Lb. to break	Defn., in.
(a)	1669	1/8	2644	7/32	15,720	7/32
(b)	1696	5/32	3000	1/4	15,860	13/64
(c)	1658	1/8	3000	17/64	15,320	3/16
(d)	1489	3/32	2688	7/32	16,440	7/32
Average	1628	1/8	2833	15/64	15,835	13/64
Tensile T. □″ ..					Ecc.	Con.
(a)	20·00		16·25		14·34	12·34
(b)	18·60		16·24		14·74	12·18
(c)	19·04		17·84		13·42	12·46
(d)	18·88		17·04		14·52	12·76
Average	19·13		16·84		14·25	12·43
Brinell :—						
Surface	277		241		207	
Centre	241		228		192	

C. I. Flywheel Mixture (Silicon % 1·4–1·6)—used for medium and heavy flywheels, turbine cylinders, steam engine cylinders (specially suitable for castings of heavy section).

Mixture		*Typical Composition*	
2 cwt.	High Silicon Hematite (Si % 6·80)	Tot. Carbon % ..	3·17
5 „	Steel (Si % 0·12)	Silicon %	1·41
½ „	Spiegel (Si % 0·30)	Sulphur % ..	0·126
12½ „	C.I. Scrap (Si % 2·00)	Phosphorus % ..	0·27
—		Manganese % ..	0·85
20 cwt.			

Silicon % (calculated) = 1·96 less ¼ loss in melting = 1·47% (nominal).



(*Micros. by J. R. Bryant*)

FIG. 137.—VARYING STRUCTURES OF FLYWHEEL MIXTURE, CAST IN S, M and L BARS, RESPECTIVELY

Graphite (× 50)	*Pearlite Grain Size* (× 1500)
(*a*)—S Bar.	(*d*)—S Bar.
(*b*)—M Bar.	(*e*)—M Bar.
(*c*)—L Bar.	(*f*)—L Bar.

To face p. 233]

MECHANICAL TEST RESULTS

B.S.I. Bar Trans. span., in	S (7/8 in. diam.) 12		M (1·2 in. diam.) 18		L (2·2 in. diam.) 18	
Carbon :— Combined % Graphitic %	0·89 2·28		0·77 2·40		0·67 2·50	
Transverse :—	Lb. to break	Defn., in.	Lb. to break	Defn., in.	Lb. to break	Defn., in.
(*a*)	1705	5/32	2464	3/16	17,829	7/32
(*b*)	1489	1/8	2441	5/32	18,144	7/32
(*c*)	1384	1/8	2441	5/32	17,667	3/16
(*d*)	1528	5/32	2240	3/16	16,262	3/16
Average	1526	9/64	2396	11/64	17,475	13/64
Tensile T. □″					Ecc.	Con.
(*a*)	17·76		16·50		14·84	13·32
(*b*)	17·72		16·20		14·80	13·40
(*c*)	17·76		16·40		14·76	13·36
(*d*)	17·76		16·96		14·60	12·92
Average	17·75		16·52		14·75	13·25
Brinell :— Surface Centre	241 235		241 223		235 212	
Micrographs :— Graphite (× 50) Gen. Struct. (× 1500)	Fig. 137 (*a*) „ „ (*d*)		Fig. 137 (*b*) „ „ (*e*)		Fig. 137 (*c*) „ „ (*f*)	

C. I. Pump Mixture (Silicon % 1·6–1·9)—used for pump casings, large pipes, condenser shells, Diesel engine frames having separate liners, turbine and other base-plates which include oil sumps; and hydraulic pressure work generally (not so suitable against temperature as Cylinder Mixture, above).

Mixture		*Typical Composition*	
5 cwt.	No. 1 Hematite (Si % 3·20)	Tot. Carbon %	3·58
1 „	Steel (Si % 0·12)	Silicon %	1·89
½ „	Spiegel (Si % 0·30)	Sulphur %	0·116
13½ „	C.I. Scrap (Si % 2·00)	Phosphorus %	0·48
		Manganese %	0·61
20 cwt.			

1·80% (nominal).

Mechanical Test Results

B.S.I. Bar Trans. span, in.	S (7/8 in. diam.) 12		M (1·2 in. diam.) 18		L (2·2 in. diam.) 18	
Carbon :—						
Combined %	0·73		0·66		0·59	
Graphitic %	2·85		2·92		2·99	
Transverse :—	Lb. to break	Defn., in.	Lb. to break	Defn., in.	Lb. to break	Defn., in.
(a)	1487	1/16	2555	7/32	12,275	7/32
(b)	1566	7/64	2307	5/32	12,902	3/16
(c)	1449	3/64	2260	5/32	13,372	7/32
(d)	1458	7/64	2374	7/32	13,901	7/32
Average	1490	5/64	2374	3/16	13,112	7/32
Tensile T. □″					Ecc.	Con.
(a)	14·68		13·32		10·36	8·96
(b)	14·96		13·26		10·28	9·32
(c)	15·04		12·84		10·74	8·74
(d)	15·08		13·34		10·34	9·22
Average	14·94		13·19		10·43	9·06
Brinell :—						
Surface	241		228		207	
Centre	217		196		163	

C. I. Soft Mixture (Silicon % 2·0–2·3) used for light base-plates, motor end plates, builders' castings, and small castings not required to be hydraulically tight and not subjected to heat in service (specially suitable for castings of thin section).

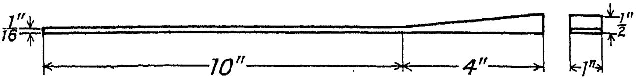
Mixture		*Typical Composition*	
3 cwt.	Hematite No. 1 (Si % 3·20)	Tot. Carbon %	3·48
6 ,,	Holwell No. 3 (Si % 3·0)	Silicon % . .	2·26
11 ,,	C.I. Scrap (Si % 2·0)	Sulphur %	0·114
—		Phosphorus %	0·63
20 cwt.		Manganese %	0·63

Silicon % (calculated) = 2·48 less $\frac{1}{6}$ loss in melting = 2·07% (nominal).

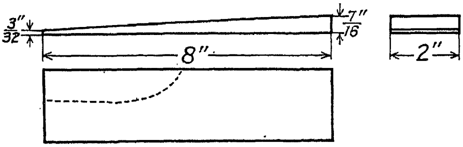
MECHANICAL TEST RESULTS

B.S.I. Bar	S (7/8 in. diam.)		M (1·2 in. diam.)		L (2·2 in. diam.)	
Trans. span, in. ..	12		18		18	
Carbon :—						
Combined % ..	0·68		0·58		0·48	
Graphitic % ..	2·80		2·90		3·00	
Transverse :—	Lb. to break	Defn., in.	Lb. to break	Defn., in.	Lb. to break	Defn., in.
(*a*)	1498	3/32	2195	5/32	12,920	5/32
(*b*)	1427	7/64	2224	3/16	12,430	5/32
(*c*)	1505	7/64	2141	3/16	12,390	5/32
(*d*)	1590	7/64	2464	7/32	12,570	3/16
Average	1505	7/64	2256	3/16	12,578	9/64
Tensile T. □″					Ecc.	Con.
(*a*)	14·52		15·58		9·80	8·12
(*b*)	14·88		12·30		9·16	8·14
(*c*)	14·77		12·04		9·78	7·52
(*d*)	14·92		11·80		9·64	7·60
Average	14·77		12·93		9·60	7·84
Brinell :—						
Surface	255		235		187	
Centre	217		196		170	

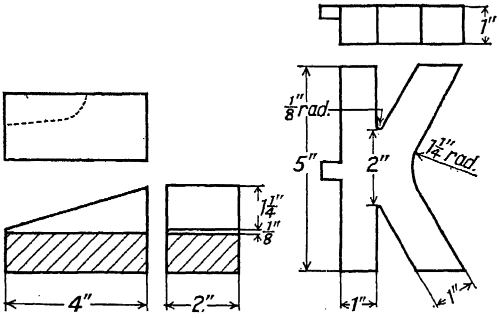
Foundry Control Tests. In the production of irons for various purposes, a number of tests can advantageously be made in the foundry, and serve to throw a good deal of light upon the properties of the metal, enabling one, for example, to determine the fluidity, the liability to liquid shrinkage, the chilling propensity, the amount of solid contraction, and so forth. Fluidity is influenced by the composition of the metal, its temperature and that of the mould, while in greensand work the amount of moisture in the sand affects the result appreciably. Silicon and carbon increase the fluidity slightly ; phosphorus very greatly, while sulphur reduces it. The influence of casting temperature upon fluidity is an obvious one. In dry-sand work, a high mould temperature promotes this quality, and the use, in greensand work, of sand containing more moisture, must naturally reduce the temperature and fluidity of the metal. For light castings, a suitable test piece consists of a strip of metal, 1 in. × $\frac{1}{16}$ in. × 12 in., run from one end by means of a standard runner. In comparing different irons, the casting temperature must be the same. The length of the strip which has been run before solidification has occurred is a measure of the fluidity of the iron. As an example, an iron containing 1·8 per cent. of silicon and 0·8 per cent. of phosphorus will fill the strip completely before



(a) Fluidity Test Bar for Large Castings



(b) Chill Test Piece for Irons of Cylinder Type



(c) Chill Test Piece for Soft Irons (d) K Test Bar for Liquid Shrinkage Test

FIG. 138.—FOUNDRY CONTROL TEST BARS

solidification takes place; while, in another, containing 1·3 per cent. of silicon and 0·25 per cent. of phosphorus, the metal was found to freeze about half way. For heavier castings, test bars shaped as in Fig. 138 (*a*) can be used.

Liquid shrinkage is generally investigated by using a K bar, having a thick central portion, as in Fig. 138 (*d*). The metal temperature and runner gate must be standardised, the small runner being permanently fixed to the pattern. After cooling, the casting is examined externally for "draws," and is then broken across at the dotted lines, to reveal shrinkage cavities. Irons having an extended range of solidification, *i.e.*, those high in silicon and phosphorus, will appear to be more solid on external examination, but spongy regions may be revealed in the interior. The irons having a short solidifying range, *i.e.*, those low in silicon and phosphorus, may show a sunken area where the figure 2 is, or draw-holes between the arms of the K on the $\frac{1}{8}$-in. radius portions, but there may be no spongy areas inside.

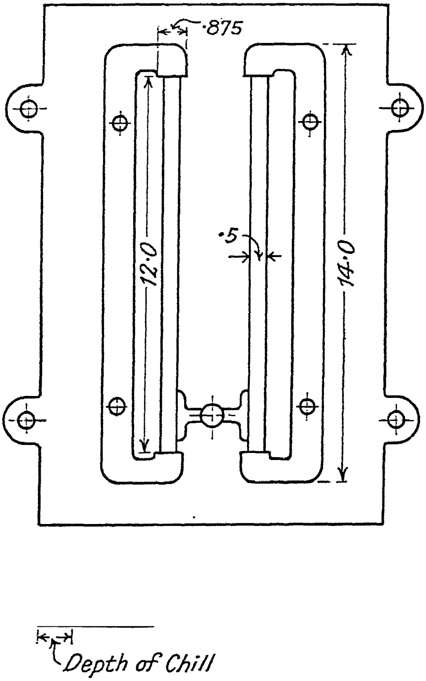


FIG. 139.—PATTERN PLATE FOR SHRINKAGE AND CHILL TEST BARS

An excellent double-purpose test, that of Keep, enables one, from one test bar, to determine both the solid contraction and the amount of chill, constituting a ready means of checking the consistency of the material. A suitable method is to cast bars, $\frac{1}{2}$ in. square and 12 in. long, as in Fig. 139, between the jaws of cast iron yokes. This figure shows the pattern plate as used in the authors' practice, except that the position of the runner has been transferred to the middle, to equalise the rate of cooling at both ends. The solid shrinkage, or pattern-makers' contraction, is determined, when cold, by measuring with a special micrometer, after which a piece is chipped off the end with a chisel, as shown at the bottom of the figure, to determine the depth to which the iron has become completely chilled. Approximate results from different irons are as follows :

Description	Contraction, in.	Depth of chill, in.
2% silicon " ordinary " iron ..	0·125	0·125
1% silicon " cylinder " iron ..	0·180	0·500
White iron	0·250	∞

In the last instance, the bar is chilled right through, from one end to the other. The test-bar patterns are first taken off the plate, and a number of yokes are cast, these being milled exactly to 12 in. between the jaws. The patterns for the test bars and runner—which is $\frac{1}{8}$ in. thick where it joins on to the test bars—are put back again, and moulded, the two yokes being placed in the mould before casting, In use, these tend to open out, and they must be rejected when a special " not-go " gauge, 12 + ·003 in. long, will just go into the jaws. Standardisation of conditions is essential for success in this test.

For a jobbing foundry having no facilities for machining, this method of testing presents some difficulty, but there are a number of tests for chill requiring no special equipment. A very simple one is to take a small sample of metal from the ladle, and to pour it into a cast iron ingot-mould, of dimensions approximately 5 in. long, 2 in. deep and $1\frac{1}{4}$ in. in mean width, and having tapered sides. If, on examining the fracture when cold, the proportion of white iron is too great, the metal is too hard, and must be softened by the use of higher silicon pig irons. If the fracture is too grey, one uses harder pig irons, or increases the proportion of steel or scrap. With the necessary experience, one can assess the quality of the metal fairly accurately by means of its depth of chill. Only irons having a low silicon content, *i.e.*, those generally termed "cylinder irons," can be tested in this manner; for an iron containing 2 per cent. of silicon would show only a white skin, of possibly 1/32 in. thick, the remainder being grey. These softer irons can be tested in the manner illustrated in Fig. 138 (*c*), where the test piece is run, from the thick end, on to a clean cast iron chill, rammed up in a greensand mould. The chill is laid on a turn-over board, and rammed up in the drag-half mould. After turning over and making the joint, the wedge-shaped pattern is laid carefully over the chill, and the cope is rammed up. When cold, the test piece is broken, at the thin end, as nearly as possible along the dotted line shown in Fig. 138 (*c*), when the distance from the thin end to the beginning of the grey portion of the fracture is the criterion. In practice, the thickness of the metal chill should be such as to lead to a depth of chill extending for about 1 in. from the end, in the case of one's standard mixture. In these tests, no coal dust must be used, and the moisture content of the sand must be constant. A convenient chill test for cylinder irons consists in casting, in a greensand mould, a wedge-shaped test piece of the dimensions shown in Fig. 138 (*b*), and run from the thick end; being broken, as in the case of the previous test, as closely as possible to the line shown dotted in the illustration. Of these various chill tests, Keep's is probably the most exact, and affords the fullest information, being, however, more expensive.

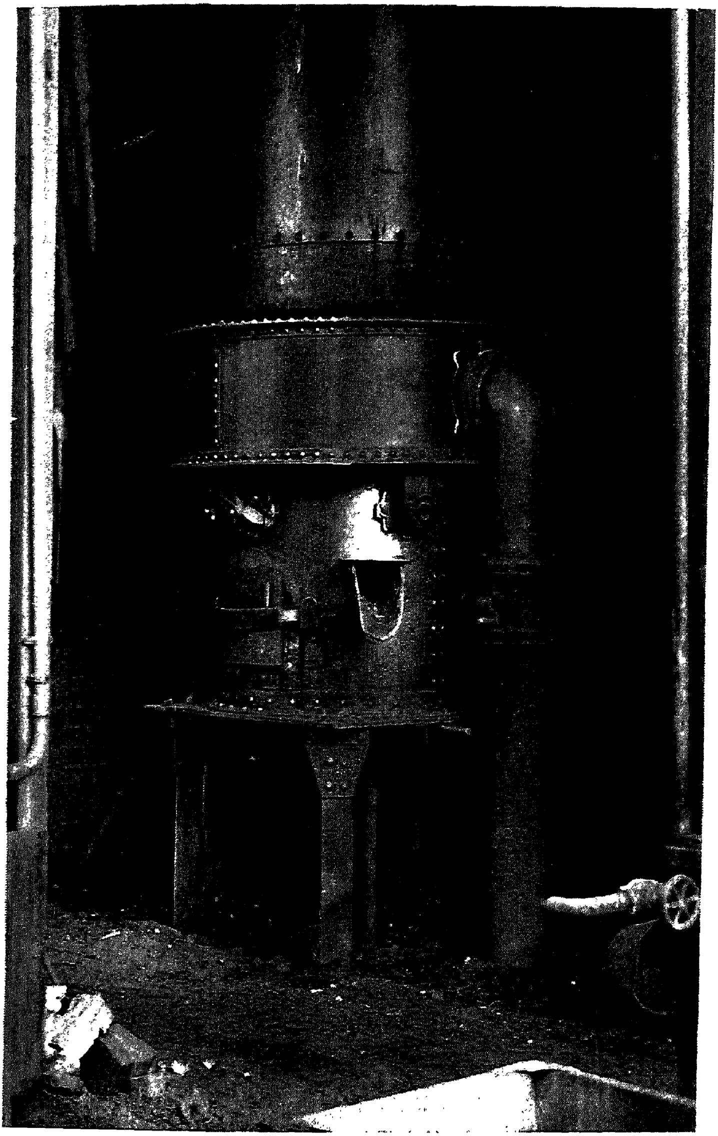
The test of fracture or grain size is made by everyone associated with iron-founding, but its indications are of a somewhat dubious nature. Some very weak high-phosphorus irons show that very close fracture which is admired by many people, while some of the modern high-duty irons have a fracture which is rather coarse. If, however, one knows the approximate composition of the metal, and has had some previous experience with it, the grain size may be a useful indication, both of strength and reliability.

CHAPTER IX

THE MELTING OF CAST IRON

For the melting of iron, the supremacy of the cupola has not seriously been challenged until the present day. It is easy to work, it has a comparatively high thermal efficiency, and it will deliver a continuous supply of molten metal over an extended period. Its disadvantages are the variations in composition of the metal melted, the large amount of carbon absorbed by contact with the fuel, and the fact that temperature control is difficult. These drawbacks have led in recent years to the introduction of other types of furnace for melting iron, and these certainly show advantages over the cupola in some respects.

Cupola Design and Arrangement. It is proposed to discuss here some considerations governing the design and arrangement of the foundry cupola, of which two typical examples are figured. Fig. 140 shows both vertical and horizontal sections of a cupola of 3 ft. 2 in. in internal diameter, in the authors' practice. Fig. 141 is of a Pneulec drop-bottom cupola, 3 ft. 6 in. in diameter, of combination wind-belt type. The melting rate of the cupola depends largely upon the internal diameter, and it may be reckoned that 10 lb. of iron are melted per hour for every sq. in. of cross-sectional area, or 24 lb. per minute for every sq. ft. of the same area. Straight-shaft cupolas are generally employed. Boshed cupolas need less bed coke, but there is more tendency towards bridging of the charge. Drop-bottom cupolas are now favoured, the outstanding advantage of cupolas of this type being that, as soon as sufficient metal has been melted, the blast can be shut off, the liquid metal drained out, and the bottom dropped, thus saving both fuel and the melting loss on any iron left unmelted, and facilitating rapid cooling,



(*Pneulec, Ltd.*)

FIG. 141.—PNEULEC CUPOLA, 3 FT. 6 IN. IN DIAMETER, OF COMBINATION WINDBELT TYPE

[*To face p.* 240

so that the cupola can be more readily repaired next day. A fixed bottom necessitates the melting down of any excess that may have been charged; further, the raking out of the residue through the breast plate is a hot and laborious job. The only disadvantage of the drop-bottom cupola is that a sand bed of the necessary consistency must be rammed on the plates for each run.

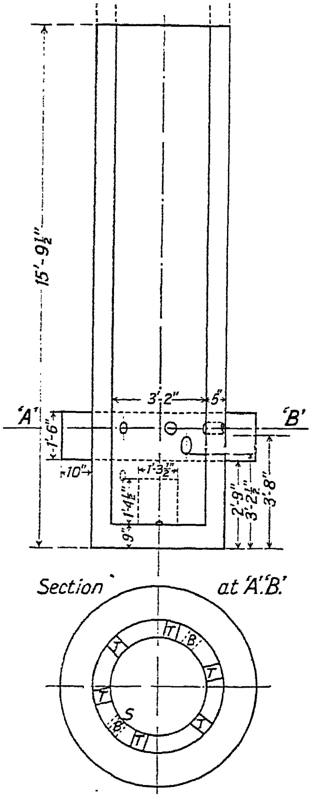


FIG. 140.—VERTICAL AND HORIZONTAL SECTIONS OF CUPOLA, 3 FT. 2 IN. IN DIAMETER

For efficient pre-heating of the charge, reduction of exhaust gas temperatures, rapid heating and economy in fuel consumption, the charge door should be at the highest practicable point, the height of the stack above this being only that necessary to provide draught for lighting up. Thus the distance between the mean tuyere level and the sill of the charge door should be from five to six times the internal diameter of the cupola at the tuyeres for a small cupola, or at least four times this diameter for a large cupola.

The depth of the cupola well is governed by the position of the tuyeres, on which the correct height of bed also depends. High tuyeres mean a higher bed, a lower pre-heating height and a greater fuel consumption, while the molten metal in the well is further away from the combustion zone, and cools more rapidly. Although a deep well must thus be undesirable, there is a lower limit, because, if there is no receiver, the bosh must be used for collecting, and low tuyeres must result in small taps. A reasonable depth is 2 feet or so, depending on the size of the cupola. If a large amount of metal is required, such as can only be accumulated by a series of taps, the use of a forehearth or receiver is an advantage. Since the tuyeres can now be much nearer to the bottom, a considerable saving in bed charge can be effected, the metal being also of more uniform composition. Unless, however, the metal is required in quantities of 2 tons and upwards, or over long periods, the loss in tap temperature more than outweighs the advantages. The floor of the cupola well should slope gently towards the tap-hole, the size of which should vary with the melting rate, being of ½, ⅝ and ¾ in. diameter for quantities of 5, 10 and 15 tons per hour, respectively. The slag-hole, which should not be near to a tuyere, may be some 10 in. from the bottom of the cupola.

In a small cupola, of, say, 24–36 in. in diameter, the total tuyere area should be about 20–25 per cent. of that of the cupola at the melting zone. In large cupolas (48–60 in. in diameter), a figure of 12½ to 16 per cent. may be used. The larger the furnace, the greater the blast pressure to ensure a proper supply of air to the centre, and thus the smaller the tuyere ratio, referring, of course, to the minimum cross-section of the tuyere. Although the cross-sectional shape is unimportant, square and rectangular tuyeres are favoured. To promote an even distribution of air and to avoid a high blast velocity at the outlet, it is advantageous to use splayed tuyeres, with the tops and bottoms horizontal, but with the area at the shaft end some 30 per cent. greater than at the wind-belt end. For large cupolas, the difference in these areas may be less. For obvious reasons, horizontal tuyeres must be better than those inclining either upwards or downwards, while the use of two rows of tuyeres close together, as in Fig. 140, appears to give the best results, particularly as regards melting rate. It is sometimes recommended to use, either two rows wide apart, or auxiliary tuyeres staggered spirally round the cupola above the lower ones. The ostensible purpose of either of these arrangements is so that the available heat lost by the production of carbon monoxide above the bottom row of tuyeres can be utilised by admitting additional air higher up the stack. But the same reduction to carbon monoxide must occur above the upper tuyeres, and, since the pre-heating height has now been diminished, the use, either of two rows wide apart or of staggered auxiliary tuyeres, does not appear to be theoretically sound. An apparent benefit by using auxiliary tuyeres may be due to the admission of insufficient air by the primary ones.

Since auxiliary tuyeres are used, however, in both the Poumay and Balanced-Blast cupolas, where in each case a high fuel economy is claimed, the matter can be regarded as debatable. The area of the blast pipe should be a little less than that of the tuyeres, the air thus entering the wind-belt at a velocity slightly greater than it has on passing out through the tuyeres. The area of the wind-belt should be at least 2½ times that of the tuyeres (or say 3 times that of the blast pipe), when the pulsations of the blower are minimised, a steady blast is ensured, and the danger of tuyeres near to the blast pipe passing more air than those away from it is avoided.

Preparation of the Cupola. The " melting zone " of the cupola is denoted by the fusion or " burning-back " of part of the siliceous lining, a little above the tuyeres, over a vertical distance depending on various factors. High blast pressures tend to raise the melting zone, those of lower pressure bringing it nearer the tuyere level. Variation in air supply gives a wider melting zone, a greater variation in composition of the metal, and is definitely bad practice. Regularity in working is characterised by a narrow melting zone. In preparing the cupola for melting, all slag and iron are first chipped from the walls, and the burnt-out places should be repaired with ganister, to bring the internal diameter to the proper size. The walls should be well moistened, the ganister being then pressed hard on, and made smooth on the surface. If the burning-back has been very severe, pieces of firebrick should be built in with the ganister. If the cupola has a drop-bottom, this is placed in position, riddled floor sand containing about 5% of moisture being rammed evenly over it, to a depth of about 4 in. The tap-hole is now made by putting on the cupola bottom a round iron or wooden plug of the diameter required, and ramming ganister round it, when the plug is withdrawn, to leave a hole as shown in Fig. 142. The parallel portion should not be longer than about 1½ in. Any metal adhering to the spout is now cleaned out, the spout itself being repaired when necessary by wiping on a little loam or ganister and then coating with black-wash.

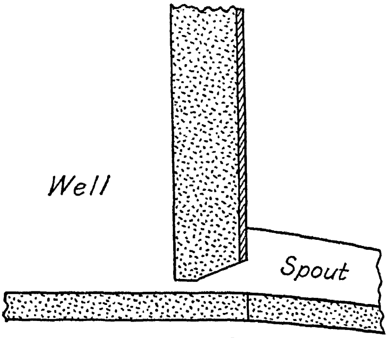


FIG. 142.—SHAPE OF CUPOLA TAP-HOLE

Charging the Cupola. A fire is started on the bottom, a little soft coke being used to assist ignition, and, when this is well alight, long pieces of cupola coke are laid in the breast-plate opening, the well being then filled up through the charging door with coke to the necessary height above the tuyeres. All the cupola apertures are left open until the coke has burnt up well above the tuyere openings. About 3 in. of sand is now rammed hard on to the coke in the breast-plate opening, the steel plate is bedded hard on to this, and fixed firmly in position by means of the crossbars and clips provided for that purpose. If the fire has not fully burnt through the bed when charging time arrives, the blast may be turned gently on, to hasten ignition between the tuyere level and the top of the bed. If it has on the other hand been standing for a long period, any deficiency in the correct height of coke must be made good. The requisite metal charge is now put on the bed, followed by alternate coke and metal, until the cupola is full to the charging door. To each ton of metal is added about 40-50 lb. of limestone, the amount depending on the quantity of sand adhering to the metal and on the ash content of the coke. Less can of course be used with chill-cast pigs, clean scrap and coke having a lower ash content, more being advisable with very dirty scrap. An excess of limestone attacks the acid lining of the cupola. A deficiency increases the metal loss, because iron instead of lime goes into the slag to form the base. It should be noted that the use of inferior ganister having a low fusing point may often cause a high metallic loss, because it softens and combines with iron to form slag.

When the cupola is being charged mechanically, little control can be exercised as to the disposition of the charge, except by somewhat elaborate structural adjustments. When charging by hand, the metal should be placed somewhat towards the centre of the cupola, and the coke more to the outside, so that the thickness of the layer of charge coke is slightly greater near to the furnace walls. It is necessary, however, that the coke should completely cover the metal charge, and a column of metal extending, in any part of the cupola, from one charge to the next, should be avoided. Even when mechanical charging is installed, it is desirable that the first one or two charges should be put on by hand, this preventing the metal from damaging the lining, and, where a chute arrangement is used, preventing the piling up of the charges at the side opposite to the charging door. As soon as the cupola is full, the tuyere covers can be closed and the blast turned on. Unless there has been a preliminary "blowing-up" of the fire, the tap-hole should be left open for a few minutes until the flame bakes the sides of the hole hard, the blast being then shut off for a few moments and the hole carefully made up with soft sand. If the fire has been blown previously, the hole can be closed before beginning the blow proper, or melting blow.

Metal should begin to trickle past the tuyeres in about six minutes after the blast has been turned on, any earlier appearance being generally associated with very cold metal, while a longer delay means that coke is being wasted unnecessarily by the use of a bed which is too high. When melting begins, attention must be paid to the tuyeres. There is always a tendency for slag and iron to solidify round them by reason of the blowing-in of cold air, and, although too much poking is to be deprecated, this building-up is prevented in practice by knocking off these pieces by means of a steel poker, pushed through the openings, after removing the tuyere covers. Any serious blocking-up caused by lack of attention can usually be overcome by closing the opening temporarily, when the blast from the other side of the cupola makes the black area once more incandescent, the obstruction then melting.

If the first metal is required for small important work, it is advisable, since the first tap is always comparatively cold, to run a few cwts., the quantity increasing with the size of the cupola, into pigs. If, on the other hand, the first 2 tons or more are required to cast one large job, it is seldom necessary with good melting practice to put any metal down. The molten metal collecting in the cupola well must be tapped out before the slag, floating on the top, reaches the tuyere level; or it will flow through these openings and solidify in the wind-belt. With constant practice, it is usually fairly easy to guess the approximate time taken to fill the well, and, as this time approaches, the slag can be seen, by looking through the tuyere spy-holes at frequent intervals, before it reaches the danger level. The tap-hole is then opened at once by means of a short thin pointed steel bar, and the metal allowed to flow down the spout into the waiting ladle. As soon as any slag shows on the stream of metal, the tap-hole is at once closed with a plug stuck on the flat end of a specially constructed "bott-stick." When "botting-up," the bott should be pushed in a direction downwards to the hole from over the stream, this preventing splashing on the hands of the operator. A convenient mixture for the plug consists of about half and half clay and coal dust, the proportions varying somewhat with the strength of the clay. A mixture of ganister and coal dust may also be used. As melting proceeds, the charges begin to sink down the cupola stack, and fresh charges should be put on, so as to keep the cupola as full as possible, and thus take the fullest advantage of the pre-heating period.

After the cupola has been working for some time, it will be found that the quantity of metal that can be obtained from one tap is considerably reduced. This is caused by the slag accumulating in the well, and this must be drawn off at intervals by opening the slag-hole behind the furnace. By opening this hole when the metal is at a lower level, and allowing the slag to flow out while blowing proceeds, until metal begins to run out with the slag, a reasonably clean furnace can be obtained. The blast is then shut off momentarily, and the slag-hole closed with a clay plug on a large bott-stick. When melting the last few charges, or "blowing-down," the resistance to the air blast diminishes as the depth of charge decreases, this often resulting in a considerable increase in the volume of air entering the cupola. Not only has this a bad effect on the metal, but it is likely to cause severe erosion of the lining. Unless, therefore, the cupola is fitted with a volume gauge, by means of which the air supply can be correctly regulated, a reduction in the air supply must be made as the level of the furnace charge falls.

Carbon Control in the Cupola. The superior qualities of irons with a low total carbon content having been emphasized, one must consider how the carbon content of the metal can be kept down in cupola melting. It is often difficult to do this very positively. Variations in melting conditions undoubtedly have some effect upon the amount of carbon absorbed, the pick-up being greater under the following conditions: (*a*) with increase in tuyere height; (*b*) with increase in the amounts both of bed and of charge coke; (*c*) when using a more reducing blast; (*d*) the lower the ignition temperature of the coke; (*e*) with increase in temperature of the molten metal; (*f*) with reduction in the rate of melting; (*g*) if tapping is intermittent instead of continuous, while the degree of absorption is also affected by other factors, these factors being of course frequently inter-dependent, and not always mutually compatible. The attainment of the desiderata often presents considerable difficulty to the average foundryman, who has to do the best he can with the cupolas he is actually using, and who, for example, generally regulates the amount of his charge coke so as to obtain maximum temperature in the metal tapped, and regards the advantage of being able to cast hot as far outweighing the drawback of the greater carbon pick-up entailed. The above considerations lead, however, to obvious deductions, as that the use of a receiver or forehearth, which permits a lower tuyere height, a lower bed charge and continuous tapping, will be advantageous in reducing the carbon content of the metal. Other special methods of reducing carbon content are sometimes employed. In that of Corsalli, the coke is drenched with slaked lime, the crust so formed rendering it more inert, so that less absorption results.

Limiting the Carbon Content of the Charge. In ordinary cupola practice, however, the most positive method of obtaining low-carbon iron is to limit the carbon content of the charge. Carbon pick-up is lower in irons with high contents of silicon and phosphorus, this being not particularly helpful, however, when making high-duty irons. Some figures for carbon pick-up in cupola melting are given in Fig. 119. Although low-carbon charges show a greater pick-up than high-carbon charges, the final figure can still be substantially lower. Thus, while metal averaging 2 per cent. in carbon as charged may be expected to contain about 3 per cent. as cast, metal averaging 2·6 per cent. in the charge should show a final figure of about 3·3 per cent. These figures are from the authors' practice, and variations will be found with different cupolas and conditions.

The necessary reduction of charge carbon can be effected by suitable choice of constituents, as by using less of the high-carbon hematites, by employing refined irons of low carbon content, and, particularly, by the addition of some 25 or 30 per cent. of steel scrap. If, as frequently, the melting conditions are such that the carbon content cannot be kept sufficiently low by regulating the amount of carbon charged, then an open hearth, electric or other suitable furnace must be employed, in which the excessive pick-up of the cupola is avoided. In the Duplex process, the metal is melted in the cupola, and then tapped into such a furnace, where the necessary additions of steel or ferro-alloys can be made, in order to arrive at the composition required, the bath being then raised to a temperature between 1,500 and 1,700° C. before casting. It will be obvious that, as well as the attainment of the "ideal" composition, the ability to superheat sufficiently has an important effect in determining the high strength obtainable by such methods. Similarly, the use of an oil-fired forehearth will enable one to de-sulphurise, make the necessary additions, and superheat as required.

Cupola Reactions. The function of the coke bed below the tuyeres, apart from the initial heating of the well, is merely to support the charges above. The top portion of the bed may be regarded as the lowest charge of coke, so that the bed is partly burnt away on top, being replenished by the arrival of successive intermediate charges, and thus, with correct practice, the same height of bed should be maintained throughout the blow. That portion of the bed which is directly opposite the tuyeres is a comparatively cold one, for the expansion of the cold incoming air, after passing the tuyeres, leads to a further drop in its temperature. In this zone, there is also plenty of free oxygen, the descending molten metal being not only cooled, but also oxidised, this effect being responsible for the loss of 6 per cent. or more of iron in cupola melting. The reaction zone between the bed coke and the incoming air is from the tuyere level upwards, and carbon dioxide is produced, with considerable evolution of heat:

$$C + O_2 = CO_2 + 14{,}550 \text{ B.Th.U. per lb. of carbon}$$

The position of the combustion zone is that of an inverted cone, with the apex at the centre, in line with the bottom of the tuyeres, and extending outwards to the lining, at a distance of 20 in. or so above. The melting zone is a little higher. It must be obvious that there is a considerable probability of iron being melted in several charges at the same time. Thus, sudden changes in composition may lead to very unsatisfactory results, even when the respective mixtures are separated by the additional charge coke. The metal descending the stack is continuously getting hotter, so that on reaching the melting zone, its temperature should be little short of the melting point, when it liquefies in the upper portion of the combustion zone, and is superheated in the lower portion, thereafter cooling again, as shown. The position of the zone of maximum temperature varies, from one cupola to another, with the design and blast conditions, but is usually from 1 to 3 feet above the top of the upper row of tuyeres, these figures—which are found from observation of the lining after the melt—indicating the exterior of the melting zone.

In the lower portion of the combustion zone, the coke is burnt almost completely to carbon dioxide. Above this, there is interaction between the gas and the incandescent coke, to produce carbon monoxide:

$$CO_2 + C = 2\,CO$$

This being an endothermic reaction, the thermal efficiency of the cupola is less, the greater the proportion of carbon monoxide in the exhaust gases. This can also be deduced from the fact that the reaction by which carbon burns—when the supply of oxygen is limited—direct to carbon monoxide, only yields 4,350, instead of 14,550 B.Th.U., per lb. of carbon when burnt to carbon dioxide. The proportion of carbon monoxide increases as the gases pass further up the cupola, and also from the centre to the walls of the cupola. It may be considered that 5 to 6 per cent. of this gas in the centre of the cupola at the level of the charge door is satisfactory, in view of the need of pre-heating in a reducing atmosphere.

Air Supply. In order to burn 1 lb. of carbon completely to carbon dioxide, 11·6 lb. or 151·6 cu. ft. of air are required. If the coke : metal ratio is 1 : 10, and the coke contains 10 per cent. of ash, the amount of air required to melt 1 ton of iron is:

$$224 \times 0{\cdot}9 \times 151{\cdot}6$$

or 30,562 cu. ft. The figure varies of course with the melting ratio, the composition of the coke and so forth, but 30,000 cu. ft. of air per ton of iron melted may be taken as a very rough working basis, although the most suitable quantity of air to supply to any particular cupola should be determined by actual experiment. For this purpose, the pressure gauge is misleading. Higher and lower blast pressures do not necessarily mean more and less air, respectively. Choked tuyeres will lead to a higher pressure, but less air is passing. A decreased resistance in the stack at the end of the blow will cause a lower pressure, but more air is passing. A volume gauge must therefore be used, preferably a Pitôt tube, reading in conjunction with a differential manometer. The questions of position, calibration and the precautions necessary in using volume meters constitute a difficult and complicated subject, and, as this has already been discussed *in extenso* by one of the authors elsewhere,* it is not proposed to deal with it here.

Cupola Blowing Machines. The air required for cupola operation is delivered either from a positive blower of the Roots or Baker type, or by a high-speed fan. Excellent results can be obtained from either type, but the blower is probably preferable for anyone not completely conversant with cupola control. This is because, in the positive blower, the revolution of the drums at a given speed sweeps out an almost constant volume of air. Any reduction in the effective tuyere area caused by slagging, or any other increase in resistance inside the cupola, will lead to a corresponding increase in blast pressure, but the volume will be practically constant. In the usual high-speed fan, the pressure would remain constant, but the volume delivered would decrease with the increasing resistance. Thus a constant resistance is essential for a fan from which a definite volume and pressure of blast are required, and there is a greater need for the installation of a volume gauge than when a positive blower is used. Fans are, however, cheaper to instal and maintain, and, if the design of cupola and pipe-line is correct, and the fan can be fitted fairly close up to the cupola, it will give equally good results. In either case, the advantages of a variable-speed motor are obvious, and the method so frequently adopted of by-passing excess air to atmosphere is much to be deprecated. In order that the air shall be properly delivered to the middle of the cupola, a higher blast pressure must be used for a cupola of large diameter than for a small one, the following being approximate figures for cupolas of different sizes :

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* R. T. Rolfe, in *Foundrywork and Metallurgy*, Pitman's, Vol. IV, p. 791.

Diam. of cupola, in.	Pressure, oz.	Ins. W.G.
24 to 36	8	13·80
36 to 48	9	15·50
48 to 60	10	17·25

Control of Cupola Working. One of the criteria of successful cupola operation is the thermal efficiency, the percentage of the total heat generated which is utilised in melting and heating the metal, this figure being readily calculable from the data given on p. 259, and following. The chief loss of heat is in the exhaust gases, where a low temperature and a high content of carbon dioxide indicate economical melting. The low exhaust temperature is most readily achieved by the use of a sufficiently high cupola, methods of recuperation not having been found very successful. If the height of bed and the proportion of charge coke are correct, too much or too little air will result in a low thermal efficiency, while, although a high efficiency may not necessarily result in the production of iron of the highest quality, yet one can operate a cupola so as to obtain maximum efficiency, without prejudice to quality.

The varying results obtained under different conditions of operation must naturally be recorded, a convenient method being the graphical one, as illustrated in Fig. 143. Effective control can be obtained only if the blast pressure is kept constant during the run. The practice of reducing the blast at intervals, for example, to enable hand-shanking to be carried on, is wasteful and unnecessary. The reduction of blast at once lowers the melting zone, and coke is consumed wastefully before the new position has become stabilised. The subsequent increase of blast, after a period of slow melting, brings hot metal into contact with free air, with consequent oxidation and loss of metal. If the metal is coming down too rapidly, the blast should be cut off entirely, when the position of the melting zone remains unchanged

Nor, as can be seen by reference to Fig. 143, does this prevent one from determining the true melting rate. Both the quantities tapped, and the temperatures, are first plotted along the abscissa on a time basis, the points on the metal curve being then set back so as to relate them to an axis of

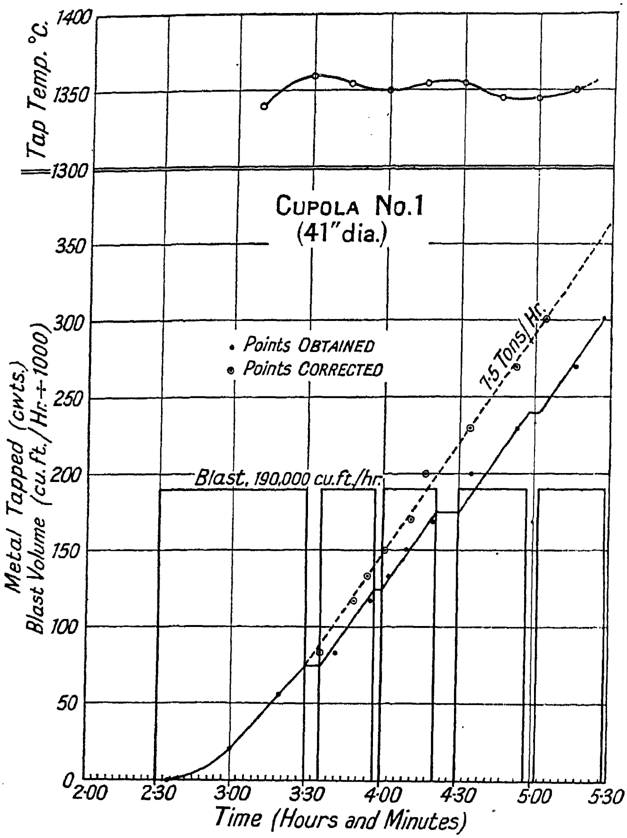
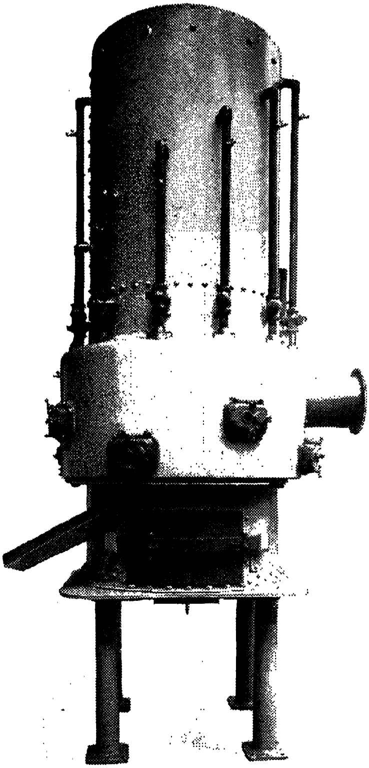


Fig. 143.—Graphical Method of recording Cupola Performance

melting time, instead of *clock* time, thus enabling the true melting rate, for any coke ratio and air volume, to be arrived at. Systematic control of blast volume, coke ratio and tap temperature—the last by means of an optical pyrometer of the disappearing filament or colour-comparison type—will enable one to establish the optimum conditions for any cupola. A check should also be kept of the wear of the lining at the melting zone, where a proper control of air should result in the reduction of the width of this zone to a minimum. According to Moldenke, a 9-in. zone can be attained, but it is frequently considerably wider in practice. The following are typical figures from the author's practice :

Diam. of cupola	41 in.
Coke consumption (total) per ton of metal melted	2 cwt. (Tredegar)
Volume of air per lb. of coke	113 cu. ft.
,, ,, ,, ton of metal melted	25,333 cu, ft,
,, ,, ,, hour	190,000 cu. ft.
Aver. melting rate, tons per hour	7·5
Aver. melting rate, lb. per sq. ft. of hearth area per min.	30·6
Aver. melting rate, lb. per sq. in. of hearth area per hour	12·7
Aver. tap temperature of metal	1350° C.

Cupola Coke. Coke for cupola purposes should be hard, strong, as compact as possible, and slow to burn, such as may well be produced by overheating. Not only has it to stand up without crushing under the weight of the metal, but the complete combustion essential in foundry work can be obtained only from coke of this variety. A soft and open coke will expose a greater surface to combustion in the upper portions of the stack, where combustion is undesirable, and will occupy when in the melting zone a greater space, and will therefore offer a greater resistance to the passage of air, when a free passage of air is so necessary. It should be low in volatile matter, moisture, sulphur and ash, with a high content of fixed carbon, a high calorific value and a low reactivity. Reactivity is determined by the rate of reduction of carbon dioxide to monoxide effected by the coke, and coke of high reactivity—as produced, for example, by low temperature carbonisation—is unsuitable for cupola melting. Tredegar coke, as used in the authors' practice, shows the following typical figures: 1·02% moisture, 0·63% volatile matter, 89·72% fixed carbon, 7·80% ash and 0·73% sulphur, with an approximate calorific value of 13,500 B.Th.U. per lb. The



(*Constructional Engineering Co., Ltd.*)

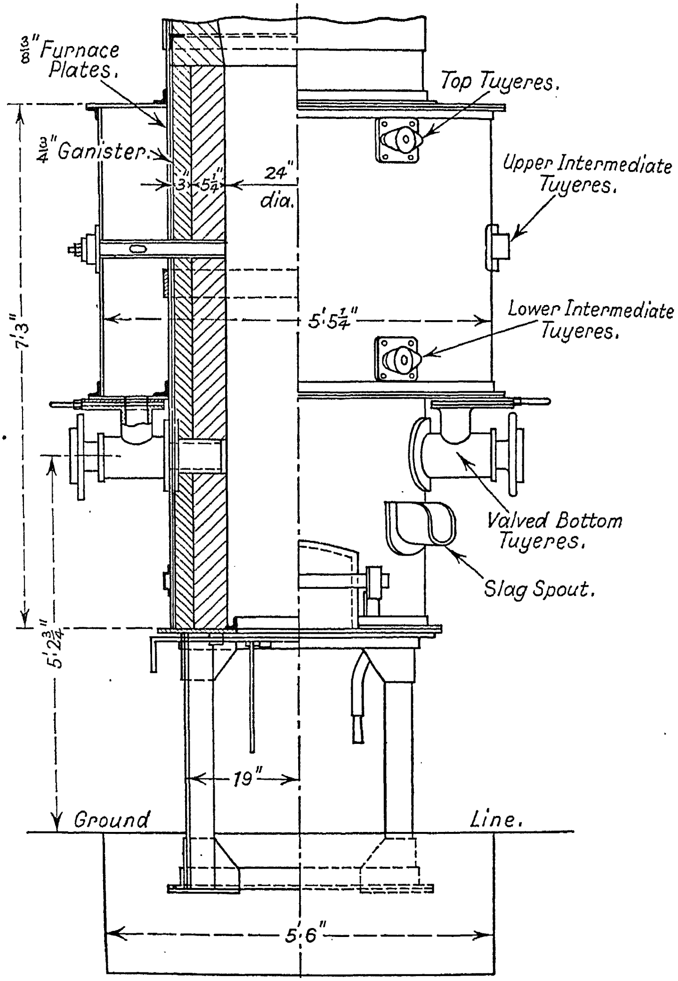
FIG. 144.—THE POUMAY CUPOLA

To face p. 255]

following are desirable maxima: 3% moisture, 1·10% volatile matter, 10% ash and 1% sulphur, corresponding to a minimum of 85% fixed carbon.

Cupola Slags. Slag is the result of the interaction between the limestone which is added with the coke, and the sand adhering to the pig iron, the ash of the coke, and, to a lesser extent, the cupola lining. If the limestone is insufficient, iron is taken up instead, the metal loss being higher. The limestone charge in practice varies considerably, from 10 to 40 per cent. of the coke charge. One must judge by experiment, and observation of the slag produced. A good slag is green or brown, brittle and glassy. If dead black, hard and stony, it contains too much iron, due to insufficient limestone. The slag also absorbs some of the sulphur of the coke, this effect being promoted by the use of a high proportion of limestone, and a small amount of fused sodium carbonate, to make the slag as basic as possible and increase its fluidity. A high melting temperature is also desirable and the slag must not be tapped prematurely from the cupola. In a satisfactory slag, the content of lime and magnesia should be at least 30 per cent., so as to minimise the loss of iron, and promote sulphur absorption. The viscosity and the iron content are excessive if the silica content exceeds 45 and the alumina 20 per cent. Iron should not exceed 12 per cent., manganous oxide 4 per cent., while the sulphur content should be as high as possible, not below 0·5 per cent., being frequently much higher.

Special Cupolas. Mention should be made of two special types of cupola, the Poumay and the Balanced-Blast cupolas, both of which employ auxiliary tuyeres. In the Poumay cupola of Messrs. Thos. E. Gray & Co., Ltd., shown in Fig. 144, incomplete combustion in the lower part of the cupola is deliberately aimed at, with intent to avoid oxidation, while the arrangement of the auxiliary tuyeres is such as to promote fractional combustion of the carbon monoxide higher up the stack, so as to impart extra heat to the descending charges, with the object of attaining hot metal and a higher fuel economy. It is claimed that the success or failure of regenerative tuyeres is entirely a question of position and arrangement, and the fact that upwards of 80 of these cupolas are now operating in this country would seem to show that the claims made are not without some justification. The Balanced-Blast cupola has been developed by Mr. J. E.



(*British Cast Iron Res. Assn.*)

FIG. 145.—THE TUYERE SYSTEM OF THE BALANCED-BLAST CUPOLA

It will be noted that the entrance from the blast main into the wind-belt is not shown in these views; while there are actually three tuyeres, disposed at 120° intervals, in each row; the top and lower intermediate tuyeres being directly above and below each other, and the upper intermediate and valved bottom tuyeres similarly situated, these two sets being at 60° to each other.

Fletcher, while a British patent has been obtained for it by the British Cast Iron Research Association. The tuyere system is shown diagrammatically in Fig. 145. It differs from the Poumay cupola in that the primary control is effected by the lower tuyeres, the upper ones being proportional to meet the requirements of the individual furnace. The row of main tuyeres and the two or more rows of smaller auxiliary tuyeres all feed from the same wind-belt. The main lower tuyeres are controllable by screw valves, capable of fine adjustment, so that the air passed through them may be regulated, while the tuyere apertures are such that, although the actual stream of air passing the valves moves at high velocity, there is a reduction in the impinging effect upon the coke, and a softer blast is produced. For any given air supply, the throttling of the valves on the main tuyeres will increase the pressure in the wind-belt, and thus force more air through the upper tuyeres, the air being thus adjusted between the lower and upper tuyeres to suit different conditions of working, the reason of the term "balanced-blast" being obvious. The extra rows of tuyeres necessitate the use of more bed coke, but, owing to the less oxidising conditions, this is said to be largely recoverable. It is claimed that, as compared with ordinary cupolas, there is a lower coke consumption, a higher melting rate, a decreased sulphur absorption and less wear on the lining. A particularly useful arrangement on this type of cupola is the slide valve which is fitted to each of the main tuyeres. These valves are closed, in turn, at about ten-minute intervals, shortly after melting has begun. Thus melting takes place from three sides, and any bridging that might tend to occur above any tuyere is obviated by closing it.

Cupola Melting Costs. The subject of melting costs is naturally of importance to the foundryman, but comparisons with those of other practice are a little difficult, by reason of the considerable variation in the cost of coke, ganister, etc., according to the distance from the source of supply. The actual quantities of the various materials used, which naturally vary to some extent with their quality, are always of interest, and the following are typical figures which refer to an output of 2000 tons of general engineering castings per annum, light, medium and heavy, there being more light than medium and more medium than heavy castings. The amount of metal melted is 4070 tons, of which 300 tons is used in casting core-irons, and 375 tons is put down as steel pig, for use in subsequent casts, the difference of 1395 tons representing melting loss, runners, risers, etc. Two cupolas are used, of 3 ft. and 3 ft. 6 in. diameter, approximate melting rates being 5 and 7 tons per hour, respectively, these being used alternately. The capital charge covers the whole cost of installation, including platform, mechanical charging arrangements, blowers, motors and so forth. The prices for materials are those ruling on July 1st, 1937. The coke figure includes the bed coke, but excludes the returns from the bed, which are used in the drying stoves. The details of melting cost are as follows :

COST OF CUPOLA MELTING

	Per ton of castings produced		Per ton of metal melted	
	s.	d.	s.	d.
Capital charge, 10% for interest and depreciation on £1,500 = £150	1	6	0	9
Maintenance, incl. materials and labour for re-bricking annually, being £50 for small and £70 for large cupola = £120 in all	1	2½	0	7¼
Ganister for patching, 78·4 lb. per ton of metal melted at 35s. 3d. per ton (mean of 32s. 1d. and 38s. 6d., two grades, used 50 : 50)	2	6½	1	2¾
Coke, 2¾ cwt. (all-in) at 39s. 6d., per ton of metal melted	11	0½	5	5¼
Limestone, 56 lb. per ton of metal melted at 11s. per ton	0	6½	0	3¼
Labour, one furnaceman and four men, at total of £800 per annum	8	0	3	11¼
Power 14 kw., 4 hours, 6 days per week, 50 weeks per year at 1d. per unit	0	8½	0	4¼
Total cost	25	6½	12	7

Comparative Costs of Melting in Different Units. The relative costs of melting in the cupola and in various other units are given by Schüz and Stotz,* an exact basis of comparison being obtained by using figures determined in all cases in melting for malleable iron castings. The following table gives the various costs calculated into English values at the average rate of exchange. Although the cost of cupola melting is somewhat higher than that just cited, it is the lowest figure given, melting in the Brackelsberg furnace, however, being very little more expensive:

Comparative Melting Costs for 1 ton of Iron in Different Units

	£ per ton
Crucible Furnace	3·564
Cupola Furnace	0·74
Oil Furnace	1·86
Brackelsberg Powdered Coal Furnace	0·78
Siemens-Martin Furnace	1·31
Electric Furnace	2·60

Some more recent figures for melting costs for cast iron are quoted by Dawson,† as follows:

Cupola	10–15	s. per ton
Crucible	55–90	,,
Rotary coal-fired	14–16	,,
Rotary oil-fired	20–25	,,
Electric furnace	50–60	,,

Miscellaneous Cupola Data. A knowledge of the following data is necessary for correct cupola control.

Data relating to Air:

Proportion of oxygen in air by weight	23 per cent.
,, ,, ,, ,, volume	21 ,,
Weight of 1 cu. ft. of air (15° C. & 760 mm.)	0·0765 lb.
Volume of 1 lb. ,, ,, ,, ,,	13·072 cu. ft.
Volume of air to melt 1 ton of iron	30,000 cu. ft.
1 oz. per sq. in. =	1·725 in. w.g.
1 in. w.g. =	0·577 oz. per sq. in.

---

* E. Schüz and R. Stotz, *Der Temperguss*, Berlin, 1930; Verlag von Julius Springer.

† S. E. Dawson, "The Melting of Grey Cast Iron in Different Types of Furnaces," *Metallurgia*, Vol. 16, July, 1937, pp. 81-82.

Data relating to Carbon and Coke:

1 lb. of carbon in burning to CO_2 generates 14,550 B.Th.U.
„ „ „ „ requires 2·667 lb. oxygen
„ „ „ „ „ 11·6 lb. air
„ „ „ „ „ 151·6 cu. ft. air
1 lb. of carbon in burning to CO generates 4,350 B.Th.U.
„ „ „ „ requires 1·333 lb. oxygen
„ „ „ „ „ 5·8 lb. air
„ „ „ „ „ 75·8 cu. ft. air
Specific Heat of Coke .. .. 0·203

As an approximate figure, 1 to 1·1 lb. of coke is burnt per hour per sq. in. of the cross-sectional area of the hearth at the melting zone, while the ratio of charge coke (excluding bed) may vary between 1¾ and 2¾ cwt. per ton of metal melted.

Data relating to Metal:

SPECIFIC HEAT

Description	Temperature	Value
Grey cast iron	Normal	0·1216
White cast iron	Normal	0·1298
Grey cast iron	Up to melting point	0·153
„ „ „	Molten	0·16

LATENT HEAT OF FUSION, GRM./CALS. PER GRM.

Description	Value	Authority
Iron	49·35	Wüst
Iron (4·227% C)	47·00	Umino, 1926
Iron (4·31% C : 1·11% Si) ..	46·63	„ „

Heat of oxidation, grm. /cals. per grm.

Silicon	6,400
Iron (to FeO)	1,157
Manganese	1,660

10-11 lb. of iron are melted per hour per sq. in. of cross-sectional area of the hearth at the melting zone.

Approx. aver. tap temperature .. .. 1350-1400° C.

Data relating to Slag:

Specific Heat, 0-1400° C. .. .. 0·3
Calories to heat to 1400° C. $=(1400 - 15) \times 0{\cdot}3 = 415{\cdot}5$
Heat of Formation minus Latent Heat of Fusion $= 50$ cals.
Total Heat of Fusion $= 415{\cdot}5 - 50 = 365{\cdot}5$ cals.

Data relating to Cupola Gases:

Weights in lb. per cu. ft. at 15° C. and 760 mm. pressure:

Air	0·0765
Oxygen	0·08455
Carbon monoxide	0·07398
„ dioxide	0·1170
Nitrogen	0·07399

SPECIFIC HEATS AT CONSTANT PRESSURE, *i.e.*, ATMOSPHERIC

Description	Temperature Range	Value
Nitrogen	0—1400° C.	$0{\cdot}2350 + 0{\cdot}000019t$
Carbon monoxide ..	0—1700° C.	$0{\cdot}2479$
Carbon dioxide ..	0—1400° C.	$0{\cdot}2010 + 0{\cdot}0_4742t - 0{\cdot}0_718t_2$
Water vapour ..	100—1400° C.	$0{\cdot}4669 + 0{\cdot}0_4168t + 0{\cdot}0_744t_2$

The carbon monoxide content of exhaust gases should not exceed 6 per cent.

The temperature of exhaust gases should not exceed 300°, or, at most, 350° C.

Conversion of CO to CO_2 in the cupola does not occur above 700° C., nor below 400° C.

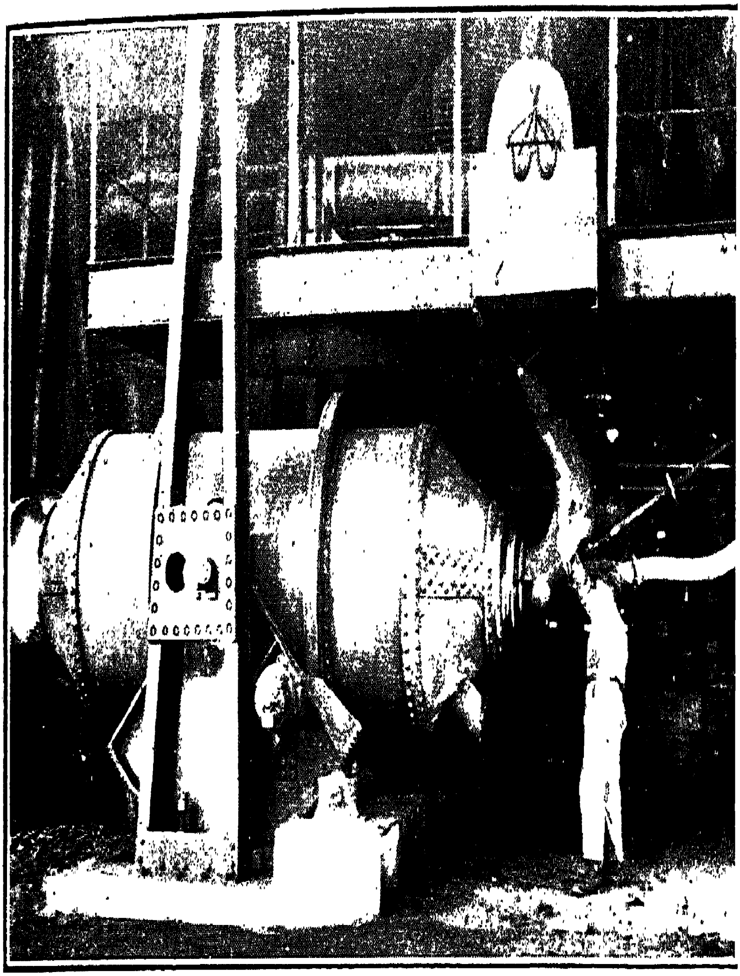
The Reverberatory Furnace. While the cupola melting of iron is much more economical, air furnaces are sometimes employed, chiefly for the production of blackheart malleable, where the composition needs closer control than is possible in cupola melting. Although the thermal efficiency of the air furnace is very low, it has the advantage of using raw coal instead of coke, while the metal does not come into contact with the fuel, so that absorption of carbon and sulphur is less, and a larger amount of metal can be tapped in one operation. Furnaces of capacities varying between

5 and 30 tons, generally from 10 to 15 tons, are used, the firebrick lining requiring to resist temperatures of about 1600° C., and the attack of a somewhat oxidising slag. The furnace bottom is generally of silica sand, but a brick lining has a longer life, and there is a saving of fuel and labour.

In the most modern types of furnace, the roof is constructed of loose arches braced by cast iron or steel frames, capable of adjustment for expansion and contraction of the bricks. Charging is accomplished by the removal of several of the rows. In furnaces fired by hand, only a limited quantity of air is admitted under the grate, a low-grade producer gas being passed into the furnace, where it is burnt by admitting secondary air through tuyeres in the roof. Pulverised fuel has recently been successfully employed in air furnaces, the fuel being much the same as in the case of hand-firing, but it must be crushed to a fineness of not less than 85 per cent. of the total to pass a 200-mesh sieve, and not less than 95 per cent. through a 100-mesh sieve, an even greater fineness being advantageous. The pressure of the secondary air must not exceed 2 oz., and the pipe lines and burners must therefore be of area sufficient to supply the requisite volume of air at this pressure. With too great a flame velocity, the life of the lining is much diminished. Firing by oil has many advantages, affording excellent control of temperature and conditions, while metal of good quality is produced, with economy in labour and maintenance costs, but there is a tendency towards greater loss of carbon, silicon and manganese.

Rotary Furnaces. The comparative lack of control of composition which is inseparable from cupola melting, coupled with the somewhat high and variable metallic losses, and the fact that the usual tap temperature is somewhat low for certain purposes, have led to the recent introduction of revolving air furnaces fired by powdered fuel, but, unlike the ordinary air furnace fired by powdered fuel, utilising the heat from the exhaust gases recuperatively. Of these, the Brackelsberg and Sesci furnaces may be taken as examples.

The Brackelsberg furnace, shown in Fig. 146, consists



(*Brackelsberg Melting Processes, Ltd.*)

FIG. 146.—THE BRACKELSBERG FURNACE, DURING ROTATION

[*To face p.* 262

of a sheet iron drum mounted on rollers, and rammed with a refractory lining. There are axial openings at each end, the powdered coal flame entering at one end from a fixed burner, and the exhaust gases escaping at the other, where they pre-heat the air blast to a temperature of at least 300° C. The exhaust opening is used also for charging, which may be done either by hand, or the furnace may be raised at this end by means of a crane, when the prepared charge slides down an elevated chute. By charging immediately after tapping, most of the furnace heat can be utilised. As soon as melting is complete, lime is added to form a slag, of which there is sufficient to protect the metal, without acting as a heat insulator. In the melting-down process, the furnace is given a rocking motion, and, when melting is complete, it is rotated at a speed of 1 r.p.m. by means of a ½-h.p. motor, this rotation enabling the bath to be heated not only from the surface, but by the absorption of heat which has accumulated in the furnace lining. Among the advantages are those of rapid melting and high tap temperature, no increase of sulphur and carbon, freedom from gases and oxides, and a superior product generally. With a coal containing 10 per cent. of ash, and with a calorific value of 13,500 B.Th.U. per lb., the fuel consumption is approximately 15-20 per cent. of the weight of the charge for malleable iron castings (poured at 1500° C.) and 12-16 per cent. for grey iron castings (poured at 1400° C.), the approximate times for the various operations for a 5-ton furnace being as follows :

1. Charging—5-10 minutes.
2. Melting, *i.e.*, from charging to tapping :
   For Malleable Cast Iron —2½-3 hours.
   Grey ,, ,, —2¼-2¾ ,,
3. Tapping, with ladles of 130-135 lb. capacity, 12-15 minutes.

The Sesci Furnace, a typical installation of which is shown in Fig. 147, is of somewhat similar type, differing chiefly in the fuel supply and combustion arrangements. In this design, the burner is carried round with the furnace, which does not rotate continuously, but is turned a full revolution in either direction after melting is completed, being previously only

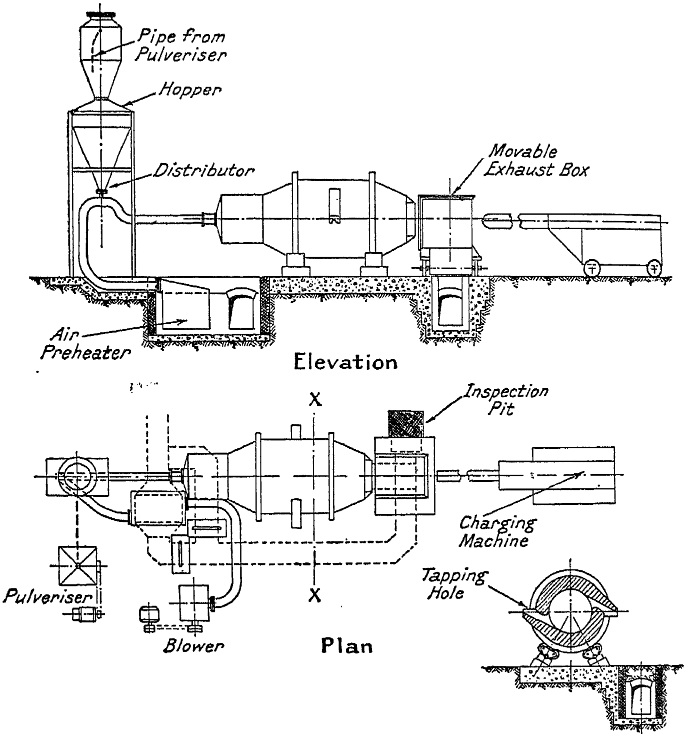


FIG. 147.—GENERAL ARRANGEMENT OF A SESCI INSTALLATION

gently oscillated. Further, there are two fuel hoppers, the furnace being started with gas coal, and changed over to anthracite when the temperature is sufficiently high, thus enabling higher blast pre-heating, and increased melting temperatures to be obtained. The air, from leaving the blower, until after combustion is completed, is in a totally enclosed circuit, being thus controllable with great nicety, so as to obtain either oxidising or reducing conditions, as desirable. One of the chief advantages of the rotary furnace is the close control of composition which can be obtained, and it is thus finding increasing application in the iron foundry for the production of malleable iron, the refined irons with a lower total carbon content than can readily be made in the cupola, and the alloy cast irons. Oil-fired rotary furnaces are also coming into use. Both the Brackelsberg and Sesci furnaces show melting costs which are of the same order as that of cupola melting, but are possibly somewhat higher, and the various advantages attending this method of melting will certainly lead to its increased employment, particularly for special work.

The Crucible Furnace. This furnace, coke-fired, is used for melting small amounts of malleable cast iron, chiefly whiteheart, for larger amounts of which the cupola would be employed. It is also used to some extent for melting the alloy cast irons. In this method of melting, there is little oxidation, and the changes, caused by melting, in the proportions of the various constituents charged, is very slight. There is no difficulty in reaching the high temperature necessary for casting small work, and an excellent product is the result. On the other hand, the fuel cost is high. The pot-melting of iron differs so little from that for non-ferrous alloys that Chapter XI should also be consulted.

Chapter X

SPECIAL METHODS OF PRODUCTION

The present chapter deals with Chilled Cast Iron and Malleable Cast Iron. The subjects of Centrifugal Castings and Die Castings have been considered of too specialised an interest to be properly discussed within the limits of a general textbook.

Chill-Castings. These are produced by the replacement of a part or the whole of the usual sand mould by metal, this, as we have already seen when discussing denseners, considerably hastening the cooling of the metal. While the object of a densener is merely to increase the rate of cooling of a thick part, so that it solidifies at the same time as a thinner portion adjoining, the purpose of using a chill is to produce locally, on a portion of the casting which is to constitute later a wearing surface, metal which, instead of being grey and soft, is white and extremely hard. In chill-cast iron, the separation of graphite—which would occur during slow cooling, and lead to the production of an iron grey in colour and comparatively soft—is almost entirely prevented by the rapid cooling, the carbon now existing almost exclusively in the combined state, as carbide of iron, Fe_3C, the fracture being brilliantly white. The chilling of cast iron may be compared with the hardening of medium- and high-carbon steel which is effected by quenching from a red heat in water, the rapid cooling of the steel causing the carbon to be retained, as Fe_3C, in solid solution in the γ-iron, to produce a mixture composed of two structurally different constituents, known as austenite and martensite, respectively, the aggregate metal being of extreme hardness. In cast iron, if the chilling is so severe as to make the whole section white, the casting is very brittle, and, although it may show excellent resistance

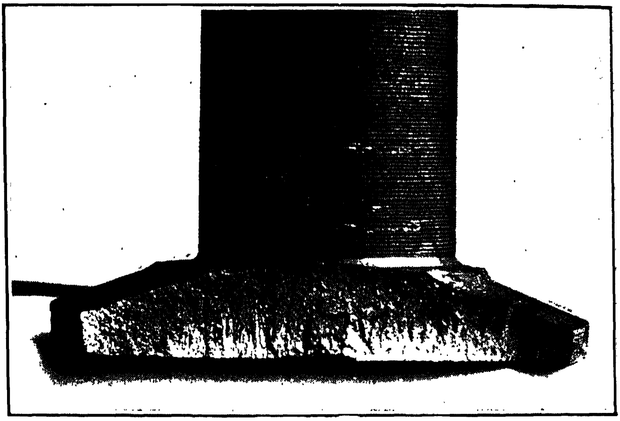


FIG. 148.—CHILLED FACE OF VALVE

To face p. 267]

to wear under certain conditions, its lack of toughness renders it unsuitable for many duties, even those where it may be subjected only to comparatively slight shocks. When correctly performed, chill-casting ensures the production on the casting of a hard white surface, varying in depth to suit the service conditions for which it is required, the interior or core being at the same time grey and tough. Frequently, only a portion of the outer surface is chilled, because it is only on this particular area that wear may be severe, and Fig. 148 shows the effect of partial chilling, where the metal is white to a depth of $\frac{1}{8}$ in. or so, near to the centre.

Chill-casting is used for the production of many types of rollers, car wheels, rolls for mills, the wearing parts of crushing machinery and dredgers, etc. A chilled roller of disc type may be made, for example, by placing a chill round the periphery of the mould after the pattern has been taken out, the print necessary for its location being fixed on the pattern, in the same manner as is used for locating a core. In other cases, the chills may be placed round or against the pattern, much as in the case of denseners. Again, the chill may be so constructed as to form a definite section of the mould, as in the manufacture of chilled rolls. Here the metal chill acts as the middle part, as in the case of the middle portion of a three-part job, an example being seen in Fig. 149. The depth of chill required in any given casting depends entirely upon the service conditions, and may vary from about $\frac{1}{8}$ in. up to nearly 2 in. In order to produce the desired effect, it is essential, therefore, that the product must be systematically controlled, particularly as regards the thickness of the metal chill and the proportions of carbon and silicon in the metal.

Casting a Chilled Roll. Fig. 149 shows diagrammatically a section through a mould assembled ready for casting a chilled roll. The thickness of the chill, A, is usually about half the diameter of the casting. The sand parts of the mould are usually rammed round a pattern centred in the end of the chill, or they may be rammed separately, if adequate steps are taken, when assembling, to ensure their concentricity. It will be seen that the mould stands in a pit on the floor, sand being filled in all round before casting, so as to promote even cooling and avoid distortion of the casting. The in-gate, C, is set so as to enter the neck tangentially, in order to produce a spinning effect in the metal as it fills the mould, and thus to promote the retention of any dross in the middle of the rising liquid, when it is much more likely to be carried up into the head, B, and so removed. The head is rod-fed, small quantities of hot metal being added from time to time, to make up for solidification shrinkage as the casting freezes upwards.

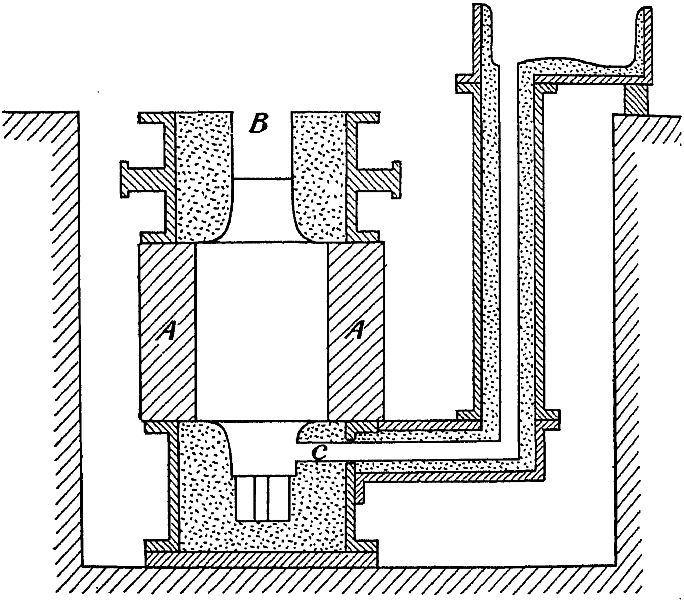


Fig. 149.—Section through an Assembled Mould for Casting a Chilled Roll

The Dressing of Chills for Rolls. The chills are cleaned well with a wire brush, and placed in the stove over night, with the sand parts of the mould. Next morning, when the temperature of the chill is about 140° C., it is coated with a special roll blacking, having a very low ash content. This blacking is prepared by first mixing with warm water, and then adding a small quantity of molasses and methylated spirits. The obtaining of the right consistency is important. It will be realised that the chill must be coated sufficiently with blacking to prevent any sticking, but, if the wash is put on in too thick a state, the rapid drying caused by the hot chill will make the surface uneven and lumpy. For this reason, some roll foundries now test the specific gravity of their blacking, by means of a No. 2 Twaddell hydrometer, when a reading between 45 and 50 degrees should be found. Three or four good coats, allowing each to dry thoroughly, should be sufficient.

Metal for Rolls. For chill-roll making, control of composition within fairly narrow limits is essential. Any variation in silicon or carbon may affect very materially the depth of chill in a casting. The composition of the metal for different sizes and purposes varies usually between the following limits: carbon, 3·1-3·3%; silicon, 0·6-0·9%; sulphur, 0·12-0·18%; phosphorus, 0·2-0·5 %; and manganese, 0·2-0·35 %. Cupola-melted metal is suitable for many kinds of rolls, but, owing to the uncertainty of the losses, the charge is usually made up on the hard side, and a sample is taken from the ladle and tested for chill before casting. If this is too severe, a proportion of soft metal is added and a further test made. If the first test is, on the other hand, too soft, the metal cannot be used—unless, as in some steel-works, means are available for adding liquid steel—and it must be cast into pigs for re-melting. Air furnaces, and sometimes electric furnaces, are also used as melting units, particularly for heavy-duty rolls, such as are employed for tin-plate mills. Each of these types possesses advantages over the cupola. In either case a lower content of total carbon can readily be obtained, and the metal can be sampled before tapping. If, after testing a small sample from the furnace, any alterations in composition are necessary, the adjustment can readily be made, and the metal tested again, before tapping into the ladle. There are no doubt instances where the harder metal obtained by cupola metal will give a longer life in service, but control of composition is too uncertain for cupola melting to be really satisfactory for this purpose.

Test for Chill-Casting. For all classes of chill-casting, it is desirable to carry out some form of rapid test, before pouring takes place, so that the chilling propensity of the metal can be determined. For cupola melting, a sample should be taken from each ladle. If, as in the case of rolls, the castings are massive, the time factor is less important, because, the pouring temperature being probably in the region of 1240° C., there is plenty of time to cast a test piece on a chill, so as to obtain a fracture approximating closely to that of the actual casting. After allowing the metal to cool for 8 or 10 minutes in the mould, it is stripped, and, after a few more minutes cooling in air, is quenched, broken and the fracture examined. When dealing with metal for small castings, the test must be carried out rapidly, in order that the metal can be poured into the moulds, while still hot enough to avoid the production of gas holes underneath the top faces. In this case, one uses a smaller test piece, preferably cast in a lighter chill. For irons low in silicon, a chill is unnecessary. The test-piece can then be knocked out of the sand as soon as it has set, and, after cooling in air to a dull-red heat, it is quenched in water and broken. Given a standard test piece, and the necessary experience, the disposition of the metal to chill can be gauged with a fair degree of accuracy, although the casting itself may differ considerably from the test piece in mass.

The Metal for Chills. The metal used for casting the chills should be low in phosphorus, 0·2 per cent. being about the maximum, the silicon being preferably from 1 to 1·5 per cent. The carbon content should be reasonably low, thus ensuring the production of a close-grained metal. Care should be taken in moulding, especially with those of the ring type, so that the chills are solid, in order that they will impart a uniform depth of chill to the final casting.

MALLEABLE CAST IRON

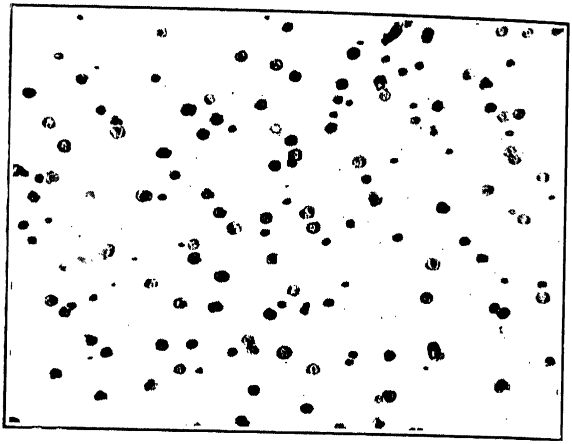
It has already been seen that the brittleness of ordinary grey iron castings is due to the breaking-up of the continuity of the metal by the presence of the thin films of graphite—having surface areas which, when compared with their masses, are very great—produced during normal cooling. Malleable cast iron is made by melting and pouring into moulds a mixture of pig iron and scrap which averages a hard mottled fracture, low in graphitic carbon, the castings at this stage being white and extremely brittle. The " malleability " is obtained by subjecting these castings to an after-process of annealing, so that the graphite is caused to separate in small rounded nodules, or rosettes, the first variety being shown in Fig. 150. Compared with their masses, the surface areas of these inclusions are very small, and therefore they break up the continuity of the metal to a correspondingly lesser degree, the greater toughness rendering such castings suitable for purposes for which the brittleness of ordinary cast iron renders that metal quite unfitting. There are two variations of the process, the Réaumur or European process for the manufacture of whiteheart malleable, and the American process, by which blackheart malleable is made. In the Réaumur method, the castings are embedded in oxide of iron, and heated to a temperature of 900° or 950° C., so that the carbon is not only very largely set free, but is also actually to a greater or lesser extent burnt away. In the blackheart method, an inert packing is used, and the annealing temperature is lower, from 750° to 850° C., so that little oxidation occurs, except at the outer edges of the casting. Both processes are commonly used in this country to-day, the respective products having their own advantages and disadvantages for the varying requirements of service.

The Whiteheart Process. In this process, various mixtures are employed, generally consisting of white and mottled hematites, with shop scrap, although bought cast iron scrap and steel scrap are frequently used. The composition varies wtih the size and kind of casting, and in the practice of the different makers, suitable figures being as follows :

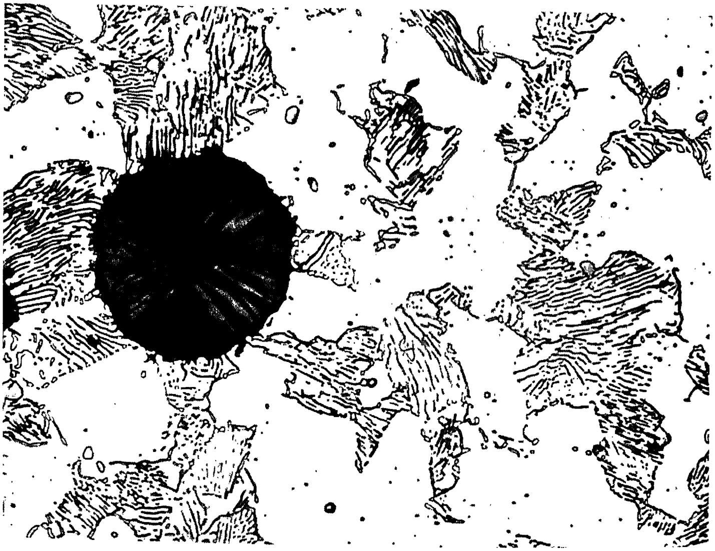
Combined Carbon %	2·50—3·50
Graphitic Carbon %	0·75—1·00
Silicon %	0·50—0·75
Sulphur %..	0·10—0·20
Phosphorus %	0·05—0·08
Manganese %	0·20—0·40

It will be seen that here there is free carbon already existing before the annealing, but, since the separation of graphite occurs at a lower temperature in the presence of a higher content of silicon, while, if the silicon is below 0·50 per cent., there is difficulty in annealing, a compromise has to be effected. If the silicon is above 0·75 per cent., the amount of graphite produced in the casting before annealing may be excessive, the ductility of the final product being thus inferior. An increase in the sulphur content has an effect similar to that attending a decrease in the proportion of silicon, retarding graphitisation, both during the initial cooling and also during annealing, so that a higher annealing temperature may be necessitated. F. H. Hurren refers to a batch of castings, containing 0·42% silicon and 0·45% sulphur, which refused utterly to anneal, although given 21 days treatment, and having to be rejected. A figure of 0·2 per cent. of sulphur should be regarded as the maximum limit, greater proportions prejudicially affecting the results given by the bend test. The manganese content should be twice that of the sulphur, whatever that may be. It may naturally be possible by special precautions to make good malleable by going outside these limits, but they constitute a good working basis. Nickel, chromium and other alloy additions are also finding some applications.

Annealing for Whiteheart. The annealing process is effected by packing the cleaned castings in iron ore contained in annealing pans, and heated in an annealing furnace, fired by coal or gas. Gas gives a more uniform temperature, and the use of the recuperative principle renders it more efficient. The castings must be thoroughly cleaned, either by sand-blasting, or, if the section is not too light, in tumbling barrels. Care in packing is essential, castings of the same class as regards mass and section being kept together, and not mixed with those whose dimensions are very different. The pans containing the heavier castings should be placed in the hotter parts of the furnace. It is necessary to ensure complete support, by the ore, of the whole length of a long thin casting, or it will distort and sag. Maximum utilisation of the space is obviously desirable. Decarburisation is best effected by



(× 20 diam.)
FIG. 150.—WHITEHEART MALLEABLE CAST IRON
Showing nodular graphite



(× 400 diam.)
FIG. 151.—THE SAME, AT HIGHER MAGNIFICATION, ETCHED TO SHOW GENERAL STRUCTURE

To face p. 273]

the use of a mixture of old and new ore, varying with the type of casting and the method of operation, the amount of new ore being increased with the size of the casting. Small light castings can be annealed in ore which has been previously used; for large castings, 20 per cent. of fresh ore should be employed. The annealing temperature is between 850° and 950° C., the duration of treatment varying with the size of the casting, the initial period being a pre-heating one, to obtain even temperature throughout, while the cooling process must also be carried out slowly, a total period of 6 to 12 days being quite usual.

The annealing process is partly oxidising and partly graphitising. Oxidation naturally proceeds from the surface inwards, so that in the thinner sections decarburisation may be complete, the annealed metal showing only ferrite and impurities. Where the section is thicker, although much of the carbon has been removed, some still remains in the combined state, distributed as pearlite through the matrix—and persisting in combination because of the high sulphur content—while the residue consists of temper carbon. It is to the removal of most of the carbon, and the consequent steely fracture of the metal, that its name, "whiteheart," is due. Fig. 150 shows the unetched structure of whiteheart malleable, with the rounded grains of graphite (× 20). Fig. 151 is from the same sample, etched, and at higher magnification, now showing ferrite and pearlite, with one of the graphite nodules. As regards the mechanical quality of whiteheart malleable, B.S.I. Specification No. 309 lays down, as minimum figures, a tensile strength of 20 tons per sq. in., an elongation of 5 per cent. on 2 in., and a bend of 45° round a 1-in. radius, using a bar 8 in. long, 1 in. wide and $\frac{3}{8}$ in. thick.

The Blackheart Process. This differs from the earlier process in that decarburisation is not designed, the malleability being obtained by the conversion of the carbon, rather than its removal. It is therefore more necessary to produce a casting which is free from graphite before annealing, by the annealing of which the temper carbon or graphite results. The great development of the blackheart process in the

United States was due to the availability of pig irons low in sulphur, thus rendering the product amenable to the precipitation of carbon, by annealing, both at a lower temperature, and for a shorter time, than was necessary in the case of the high-sulphur materials of our own country. The popularity of blackheart is now increasing in this country, a method of overcoming the high-sulphur content of our low-silicon pig being to make a refined iron which is desulphurised in a ladle or receiver before pigging. This method is now used, both by manufacturers of refined pig iron, and by makers of blackheart malleable, who can thus produce their own refined iron. The composition before annealing should be approximately as follows :

Carbon, combined %	2·3—3·0
Silicon %	0·7—1·0
Sulphur %	0·03—0·08
Phosphorus %	0·20 (max.)
Manganese %	0·25—0·35

It is an advantage to keep the carbon lower than in the case of whiteheart, because of the effect of this element upon the strength and ductility, *i.e.*, since the annealed structure should consist of ferrite, with carbon nodules scattered through it, increasing quantities of carbon must lead to a falling-off both in the strength and ductility. On the other hand, if the carbon content is too low, there is a shorter freezing range, and it is very difficult to obtain sound castings. Since the effects of the other constituents must be generally much the same as in the whiteheart process, it should be unnecessary to give much space to them here. The question of sulphur has already been dealt with, and, since the annealing temperature is substantially lower than in the whiteheart process, a higher proportion of phosphorus can obviously be permitted. The inert packing material for blackheart is usually sand, ground slag or mill scale, and contains little free oxide, although a little oxide of iron may sometimes be added, in order to accelerate the action and promote surface decarburisation. Although annealing could be performed at a temperature of 750° C., while also, the lower the temperature of graphitisation, the more compact is the carbon, and the greater the malleability, yet the undue length of time it would take to anneal at this temperature makes a somewhat higher temperature, of about 850° C., advisable. The duration of the annealing in this process may be from some 50 to 80 hours, substantially less than in the whiteheart process. A typical example of blackheart malleable shows ferrite crystals with temper carbon distributed through them, a little pearlite sometimes remaining, this being without prejudice to the quality of the material, and leading, in fact, to an increase in strength. The mechanical test results that are obtainable from blackheart malleable of good quality can be judged from the requirements of three different specifications, as follows:

Specified Requirements for Blackheart Malleable

Specification	Y. Pt., T.□″ (min.)	Ult. Str., T.□″ (min.)	Elongation, % (min.)	Bend Test (T.p. 8 in. long, 1 in. wide and ⅜in. thick, bent round a radius of 1 in., minimum angle)
B.S.I No. 310	—	20	7·5	90°
S.A.E. Standard	—	20·29	7·5	—
A.S.T.M.—A47	14·50	22·32	10·0	—

The two American specifications give the requirements in lb. per sq. in., and the figures have been converted. Compared with whiteheart malleable, the requirements of which have already been given, the superior ductility of blackheart will be noted, better elongation and bend figures being demanded.

Comparison between Whiteheart and Blackheart Malleable. Comparison between the two products is rendered difficult by the fact that, while blackheart castings, apart from the decarburised skin, are fairly homogeneous, the structure of thin sections of a whiteheart casting differs markedly from those of the heavy portions, the former being completely decarburised, while the latter may show a combined carbon figure up to 0·9 per cent. in the middle, varying gradually to nil at the surface. Thus, all sections of blackheart are reasonably malleable, but only the thinner sections of whiteheart can be thus described. In thin castings, there is probably little difference in ductility between the two varieties, but, in those of heavier section, blackheart has the advantage. On the other hand, by reason of the higher content of combined carbon, whiteheart should be slightly stronger. These conclusions are confirmed by the results of similar test bars, 0·63 in. in diameter, of the two materials, respectively, made by a well-known foundry in the Midlands, commonly making both varieties, and the figures are quite typical of their general practice.

Variety	Tensile Strength, tons per sq. in.	Elongation, per cent. on 2 in.
Blackheart Malleable ..	23·0	12·25
Whiteheart Malleable ..	24·0	6·0

In the matter of general uniformity and machining quality, blackheart has the advantage. For strength, rather than ductility, whiteheart should be chosen—blackheart, where it is question of ductility, rather than strength. Where the castings have to be brazed, or subjected to other operations entailing the application of heat, whiteheart is superior, for, in blackheart, with its higher content of free carbon, there is a much greater possibility of this becoming combined once more, with consequent loss of ductility. In whiteheart, the much smaller quantity of free carbon renders this probability less likely.

CHAPTER XI

NON-FERROUS FOUNDING

Non-ferrous founding differs from that of iron in the much greater value of the metal, and the consequent diminished thickness of the castings. Moulding thus requires greater care, but, owing to the lesser variation in size and shape of the casting, it scarcely requires the same initiative.

Moulding Sands. Since casting temperatures are much lower, the prejudicial effect of casting is less, and the addition of new sand can thus be reduced to a minimum. For a smooth skin on greensand castings, a fine-grained sand, as Erith or Mansfield, must be used. Many of the molten alloys are very penetrative, so that an open and porous sand results in rough castings. Thorough mixing and a low moisture content are desirable. Too much moisture, although insufficient to produce blow-holes, may cause small cracks on the surface on contact with the molten metal, a rough surface resulting. To obtain a close texture in the sand, and therefore a fine skin on small castings, the sand should be lightly milled and then aerated in some manner. For dry-sand castings, fineness is less requisite, the coating applied before or after drying preventing penetration.

Ramming and Venting. The greater penetration and greater density necessitate even ramming of the mould face, avoiding soft spots, particularly on vertical walls. Venting need not be so thorough as for cast iron, but projecting parts of the mould, partly surrounded by metal during casting, must be effectively vented, or blow-holes may be found on machining. Moulds for large castings, or even for small ones, if they are important, must be dried in a stove completely, particularly for phosphor-bronze or similar searching alloys. For less-important small work, skin-drying is satisfactory, closing the moulds only when comparatively cool, and then casting at once, or the surface may again become damp, with unhappy results.

Gating for Gun-Metals. The gating of the non-ferrous alloys in general differs fundamentally from that for cast iron. Largely because of the lack of this knowledge, the transfer of men from one branch to the other is not very successful. Gun-metals should usually be run rapidly, although the design of a particular casting may sometimes cause better results with comparatively slow pouring. The gates should be so designed that solidification is progressive from the wall of the casting adjoining the gate, to the runner cup or bush. An example is shown in Fig. 152 (*a*). To obtain a sound casting, the flange A must solidify before the gate B. Although soundness is the first consideration, melting costs are much higher and losses more expensive than with cast iron, and the size of gate must thus be kept as small as possible, consistent with good results.

Fig. 152 (*b*) shows a thin-walled casting where a comparatively small runner gate will suffice, but it must be large enough to permit the metal to fill the mould freely. Heavy masses, if not fed by the runner gate, require a feeding riser, as shown at A. To obtain soundness in a large boss, or other heavy mass, one commonly increases the head of metal in the gate, to produce a corresponding increase in pressure. In tin-bronzes, however, most porosity is due to solidification shrinkage, and head pressure is effective only on maintaining a liquid channel through the gate during the solidification of the casting. Feeding is generally better when using risers as in Fig. 152 (*c*) at C, ensuring solidification of the casting before the riser. Another method of promoting feeding is to stop pouring as soon as the metal appears in the risers, when hot metal is poured from the ladle directly into them. The metal which has flowed through the mould, with consequent cooling, is displaced by much hotter metal, delaying solidification and improving feeding through the risers.

Small gun-metal castings with heavy bosses, which are difficult to feed adequately through the risers, may be poured through a large gate directly on the boss, the local heating of the sand by the metal maintaining a liquid column until the casting below has solidified. A good method of gating for this class of work is shown in Fig. 153, for a pair of small bushes. The first metal to enter falls to the bottom of the gate, and passes into the mould *via* the lower in-gate, thus forming a cushion for the metal which begins to fall almost at once from the upper in-gate. For large cylindrical castings of gun-metal, however, direct top-pouring cannot be recommended, because, when poured at such a temperature as

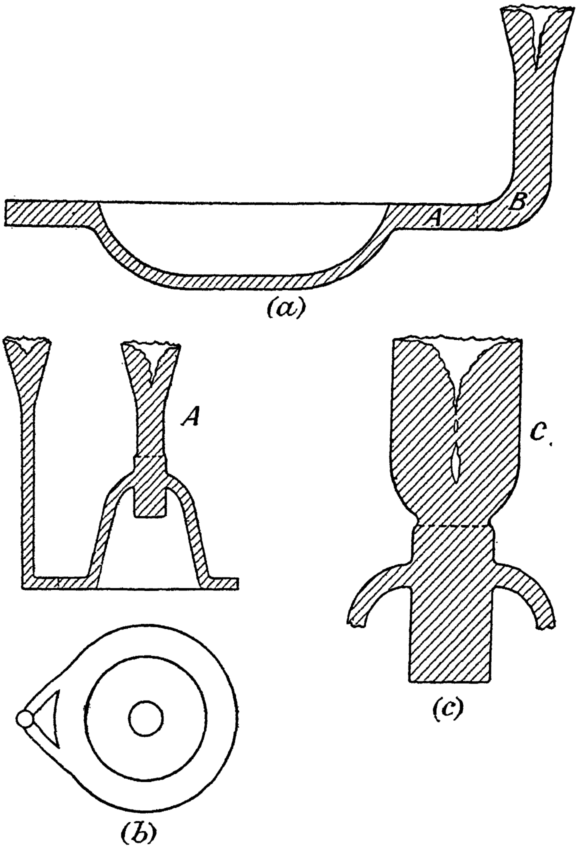


Fig. 152.—Gating for Gun-Metal: (*a*) Gate Design allowing Progressive Solidification to Runner Bush; (*b*) Application of Comparatively Small Runner Gate; (*c*) Self-Feeding Riser

to promote soundness, the metal is likely to lack the fluidity necessary for the free escape of air entrained by the stream. With all non-ferrous alloys, fillets should be used generously at the junctions of all gates, providing that the increase in mass is not such as to make it difficult to feed adequately by the column of metal in the gate above. Because of the comparatively low fluidity of gun-metals at correct pouring temperatures, the runner cups or bushes should be funnel-shaped, as shown in Figs. 152 and 153. As the metal then pitches directly down the gate, the cups must be quite clean, and one must skim all dirt from the metal surface before pouring, to ensure sound castings.

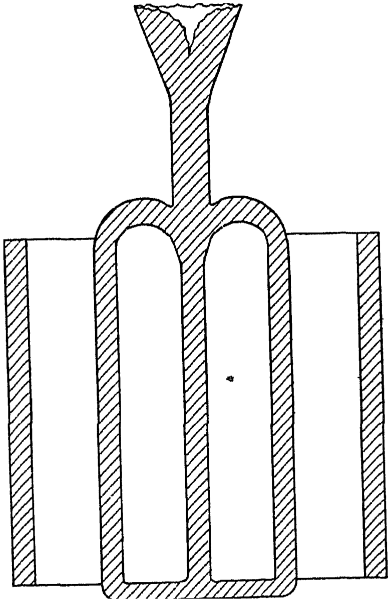


FIG. 153.—METHOD OF GATING A PAIR OF SMALL BUSHES

Mould Dressings. For small greensand castings, a clean finish is obtained by dusting on terra-flake, which affords better illumination of pockets, etc., which must be clear before the mould is closed. Excess powder must be blown off, to prevent it getting into the metal. Plumbago is also a good dressing, but gives a darker skin, of no consequence, however, if the castings are to be sand-blasted or pickled. For dry-sand moulds and cores, a mixture of terra-flake and plumbago, bonded with a little clay, is excellent.

Melting of Gun-Metals. These alloys are melted either in crucible furnaces, of pit or tilting type, and heated by coke, oil or gas ; or in reverberatory or air furnaces. In this country, the application of electric furnaces is restricted ; but, in the United States, where power is cheaper, they have considerable vogue. Crucible melting is superior to all types except the electric furnace, so protecting the metal from contact with open flame or furnace gases that the metal loss is lower. The tilting crucible furnace, with its higher thermal efficiency, and the longer life resulting from the support afforded by the casing, is preferable to that of pit type. When using crucibles, melting losses are lower than in the air furnace, where, particularly with high-zinc alloys, heavy losses may be found. With gun-metal, where a large quantity may conveniently be melted in an air furnace—crucibles being less practicable for melting 3 or 4 tons of metal for a large casting—the loss usually exceeds 2 per cent., two or three times as much as in crucible melting. Recently, the small oil-fired tilting reverberatory furnace, and another open-flame furnace of similar type, have been developed for non-ferrous melting. While the metal losses in these are doubtless lower than in ordinary air-furnace melting, while the thermal efficiency must be much greater, the objections as to contact with flame and gases must still apply. Each of these types, however, has no doubt a particular field of utility.

In the melting of 88 : 10 : 2 gun-metal, a 1-in. layer of charcoal, in pieces the size of hazel-nuts, is put at the bottom of the crucible, and the copper is melted, when a little more charcoal is added, if necessary. The tin and zinc are added in this order, the melt is stirred with a graphite rod and cast at a temperature of about 1150-1200° C. In a 250-lb. oil-fired crucible furnace, the first heat may take about an hour, the time decreasing to about 40 minutes when the furnace and crucible have become really hot, the average oil consumption being about 17 lb. per 100 lb. of metal melted.

In a 250-lb. coke-fired furnace, the first heat may take about 1¾ hours, or a little more, decreasing to 1 hour or so for subsequent melts, the average coke consumption being about 26 lb. per 100 lb. of metal melted. The view, sometimes expressed, that gun-metal should be melted slowly, is of course quite erroneous, for this must tend inevitably to greater contamination.

The Use of Fluxes. Charcoal is undoubtedly the best cover, and the practice, occasionally met with, of melting gun-metal without a cover of any description, is quite incorrect. A flux may, however, be used, and the question of fluxes is a somewhat debatable one. The chief functions of a flux are to produce a cover on the surface of the liquid metal, so as to prevent contact with the air ; and to promote liquidity of the metal, by cleansing it of the oxides, dirt or other impurities which may be mixed with it. A flux may be composed of any one, or any mixture, in varying proportions, of such substances as fluorspar, borax, chalk, sodium carbonate, sal-ammoniac, manganese dioxide, etc., all of which have definite and different uses in the melting of metals. Thus borax forms a liquid cover and dissolves metallic oxides; both fluorspar and sodium carbonate form a liquid cover and flux off siliceous matter, *i.e.*, if dirty borings are present; sal-ammoniac reacts with the oxides of zinc and aluminium, to convert them to chlorides—the operation of the different fluxes being too lengthy a matter to discuss here. It will be obvious, however, that a flux which is quite suitable for one alloy may not be satisfactory for another. The presumption is that the supplier of a flux for any specific purpose has assured himself that his compound is suitable for the particular alloy. In many cases, however, the claims are too wide, Indeed, one might from the advertisements suppose that the particular flux being recommended was a cure for all the ills that bronze castings are heir to, and that the whole secret of successful melting is comprised in the flux. This, of course, is very far from the truth. No flux can possibly correct the results of an unduly high casting temperature. There is also no doubt whatever that one can melt bronze quite successfully without using a flux.

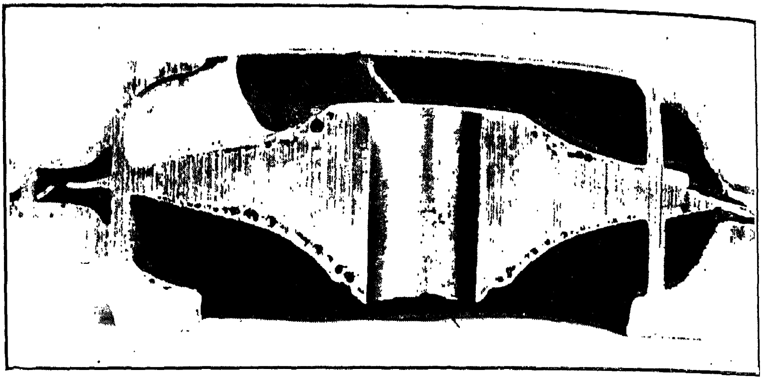
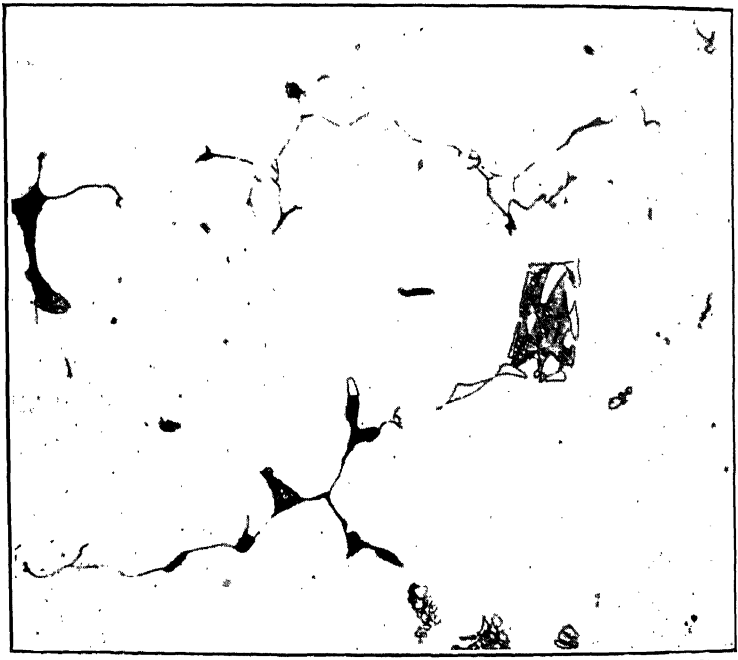


FIG. 154.—GUN-METAL IMPELLER, SHOWING GAS-HOLES UNDER SKIN, DUE TO CASTING AT TOO HIGH A TEMPERATURE



(× 400 diam.)

FIG. 155.—GUN-METAL, SHOWING INCIPIENT SHRINKAGE

To face p. 283]

The Effect of Casting Temperature. Perhaps the most vital factor in the production of sound gun-metal castings is the use of a correct casting temperature. It is certain that pouring at wrong temperatures is responsible for a considerable number of defective castings, usually for one or the other of the two following causes :

(*a*) Cavities caused by gas liberation.

(*b*) Shrinkage cavities (massive), or incipient shrinkage (generally intercrystalline).

It should be appreciated that, unlike water, where the capacity for dissolving gases decreases with rise of temperature, molten metals absorb more gas as the temperature increases, this gas being partly released as the metal cools down, and a further amount on solidification. Heating the metal to a high temperature, and casting at that temperature, thus leads to an excessive liberation of gas. The metal in contact with the sand, particularly in greensand moulds, is rapidly chilled, a solid outer skin being formed very quickly, when the gas liberated from the more slowly cooling metal within cannot escape, but is trapped beneath the impermeable outer layer, to be revealed on machining. An example is seen in Fig. 154.

While cavities caused by gas liberation are generally quite visible to the eye, shrinkage cavities—intercrystalline fissures due to voids caused by shrinkage, either of the massive or incipient type—are less obvious, frequently requiring, as with the incipient shrinkage, microscopic examination to reveal them, an example being shown in Fig. 155. The amount of this porosity is greater with higher casting temperature, and in the presence of a reducing atmosphere. Furnace atmospheres should either be neutral, this condition, however, being difficult to maintain, or slightly oxidising. One sometimes encounters red, brown and multicoloured fractures in cast bronze, these being often ascribed to oxidation. The effect is frequently local, a homogeneous yellow fracture being found only an inch or so away from the affected region, which clearly does not represent the condition of the metal as a whole. These colours arise from gas reactions during solidification, are another result of overheating, and can often be corrected by re-melting and casting at a correct temperature. The most usual result of overheating, however, is the evolution of gases during solidification, such as would probably be avoided by allowing the temperature to fall to about the correct figure before casting. But this "gassed" metal can usually be made quite sound by re-melting and casting at that proper temperature. Incipient shrinkage is rather an accompaniment of overheating, not being so completely corrected by cooling to normal temperature, although the effect is much reduced. It is largely a function of the gating and feeding of the casting, and not primarily due to the condition of the metal. Unsoundness may also be due to the presence of certain impurities in excess.

Chilled gun-metal castings are cooled so rapidly that there is insufficient time for the liberation of dissolved gases. The heavier sections are more unsound than the lighter sections of a sand casting, as shown by the results from an impeller casting, as follows:

	Heavy Boss (4 in. thick)	Thin Blade (0·325 in. thick)
Specific Gravity ..	8·45	8·70
Ult. Stress, tons/in.^{2}..	11·7	16·8
Elongation % ..	10·0	30·0
Brinell (500 K.) ..	62·5	69·1

This will explain the lower results of test pieces cut out of the casting than from the test piece attached, a variation which can be reduced by increasing the amount of head. Low-temperature casting is less prejudicial, but may result in the entrapping of air or gas in the sluggish metal, or a "cold shut," while the strength is lower. A range between 1150-1200° C. constitutes a good working basis, but it is possible to pour massive castings below the bottom limit of temperature, and small ones above the top limit, while still obtaining satisfactory results. Because of the fumes, radiation and optical pyrometers are useless in bronze and brass casting. One must use an immersion one, of thermo-electric type. Recommended temperatures for other bronzes are as follows:

Alloy	Composition					Pouring Temperature, deg. C.	Authority
	Copper %	Tin %	Zinc %	Lead %	Phosphorus %		
Lead-Bronze	84	8	—	8	—	1100	C. W. Miller, 1931
Zinc-Bronze	88	6	6	—	—	1130 (sand)	F. W. Rowe, 1924
Proprietary Bronze	80	4	Bal.	0·5	—	1120–1170	Makers
Phosphor-Bronze	88·7	11	—	—	0·3	1050–1070	R. J. Anderson, 1927
do.	85	14·25	—	—	0·75	1050–1100 (sand) 1200 (chill)	The Authors, 1932
do.	Bal.	10·5-13	—	—	0·10-·05	1230–1290 (chill)	F. W. Rowe, 1930

The Structure of Gun-Metal. It will be seen from the copper-tin constitutional diagram, part of the copper end of which is shown in Fig. 156,* that the 10 per cent. tin alloy, when solid and in a state of equilibrium, must be composed entirely of α-solid solution, and can contain none of the δ-constituent, which is only found in alloys which have reached equilibrium, if they contain at least 13 per cent. of tin. But the cooling curve (*a*), showing, by the peak at 765° C., the formation of the β-constituent, has a further peak at 455° C., which must represent the decomposition of

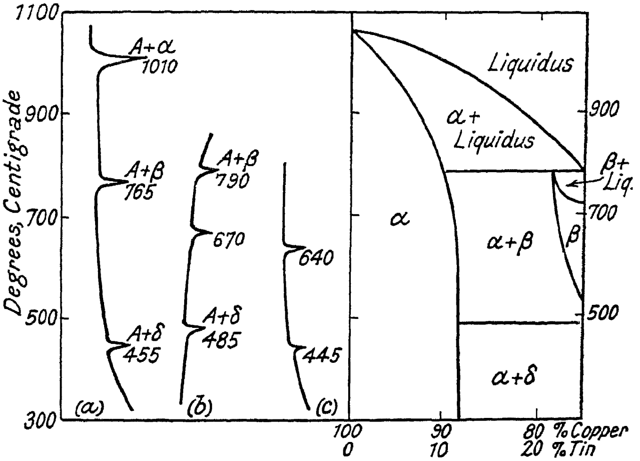


FIG. 156.—PART OF CONSTITUTIONAL DIAGRAM OF COPPER-TIN ALLOYS, AND COOLING CURVES FOR GUN-METAL (H. S. AND J. S. G. PRIMROSE)

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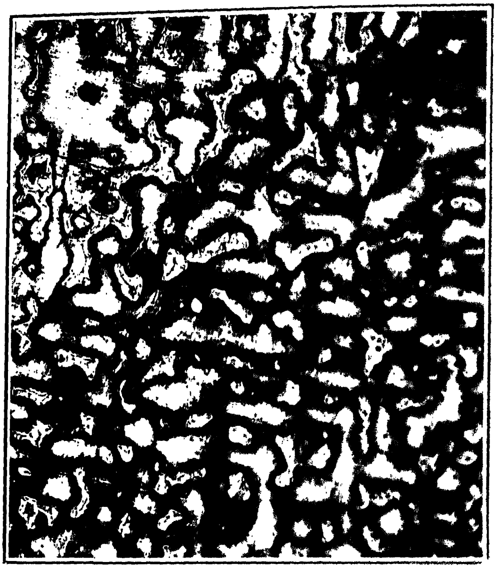
* From a paper by H. S. and J. S. G. Primrose, *Journ. Inst. Met.*, No. 1, 1913, Vol. IX, Fig. 6.

β into $\alpha + \delta$. The usual structure of this alloy, shown in Fig. 157, thus represents a metastable condition, the stable state resulting, either from a more prolonged cooling after casting, or a subsequent annealing, when the δ-constituent is entirely absorbed into solid solution. In the example shown, the matrix is of primary α, showing a cored structure, while the isolated areas are the $\alpha + \delta$ eutectoid (duplex), with a border of white δ.

The Mechanical Quality of Gun-Metal. Both the B.S.I. and Admiralty specifications for this alloy require a minimum tensile strength of 16 tons per sq. in., with a minimum elongation of 8 per cent., the last figure being somewhat exiguous. In gun-metal, unlike steel, the greatest strength is always associated with the highest elongation. Sound metal is naturally stronger than that which is unsound, and casting at correct temperature is therefore best calculated to give maximum strength. The metal must also be sufficiently free from impurities, some of which affect prejudicially the strength, soundness and other properties. The maximum limits for the various impurities are about as follows: aluminium, 0·05%; arsenic, 0·60%; antimony, 0·50%; lead, 0·50%; silicon, 0·05%, and sulphur, 0·05%. Lead up to a content of 1, or even 1½ per cent., increases the strength and ductility of gun-metal, but a maximum of 0·5 per cent. is laid down by each of the specifications referred to, possibly because of the segregation sometimes found in bronzes containing lead.

Phosphor-Bronze. The presence of phosphorus in tin-bronze makes the liquid metal very fluid, and prolongs the solidification range considerably. A different technique is therefore required. Casting in chill moulds, reducing the freezing range, increases soundness, density, strength and hardness, the ductility being correspondingly reduced. Except for very small castings, dry-sand moulds are preferable to those of greensand, being more suitable for use in conjunction with local chills, without which some types of casting cannot be made quite sound. When the mass is not great, it is generally better to use small runner and riser gates, rather resembling those employed in iron foundry practice,



(100 diam.)

FIG. 157.—GENERAL STRUCTURE OF 88 : 10 : 2 GUN METAL

(*Micro. by J. R. Bryant*)

[*To face p.* 286

than those usually adopted for gun-metal. If the casting includes a large mass, as a heavy boss or flange, the effect of liquid shrinkage must be counteracted. On less important work, large risers will effect this purpose, but, as they increase the mass and therefore retard solidification, the density of the metal is reduced. When, therefore, there is large variation in mass, and the casting after machining must be hydraulically tight, smaller risers should be used, the shrinkage effect being counteracted by means of chills. Runner bushes should be of ample size, so as to maintain a good head of metal, and prevent dross from entering the mould. If desired, plugs or stoppers can be used, but the great fluidity of phosphor-bronze tends to allow the metal to filter past them, especially when dried runner bushes are used. Dross can successfully be prevented from entering the mould by using a small piece of copper sheet, almost covering the top of the gate.

The use of a correct casting temperature is important. It is a little difficult to give definite figures, because the optimum pouring temperature varies with the design and mass of the casting, and the composition of the alloy. With important work, if a number of castings are being made from a particular pattern, it may be necessary to establish the correct temperature by trial. The following ranges of temperature may be taken as a general guide:

POURING TEMPERATURES FOR PHOSPHOR-BRONZE CASTINGS

Type of casting	Phosphorus, per cent.	Pouring Temperature, ° C.
Castings of small and medium size, wall thickness $\frac{1}{4}$–$\frac{1}{2}$ in.	0·2	1120–1150
	0·6	1070–1100
As above, but with wall thickness $\frac{3}{4}$–$1\frac{1}{2}$ in.	0·2	1090–1120
	0·6	1025–1070

The fracture of the metal constitutes a reliable guide as to correctness of pouring temperature. Except on very thin sections, a phosphor-bronze casting of good quality shows a very shallow skin, bluish-grey in colour, the remainder being golden with a clearly-defined dense crystal structure. The use of an improper pouring temperature gives rise to a fracture of mixed colours, which, when examined under low-power magnification, reveals a loosely-knit fern-like structure.

The Casting of Brass. A typical example of brass melting is involved in the production of brass shells for tube-drawing, these being made by casting the 70 : 30 alloy round a sand core in an iron chill. The mould may either be a split or a cannon mould. A split mould consists of two semi-circular longitudinal sections, machined to a good fit and held together by cramps, the core being carried by collars fitted at the top and bottom. The metal is poured down an inclined spout, which is cast on to the back half of the mould. Cannon moulds are hollow cylinders, fitted at the bottom with a recessed collar to hold the lower end of the core, the upper end being secured by a ring, fitted with three wings, to permit the metal to pass round the core in pouring. The chills are coated with a mixture of oil and charcoal. The production of a sound billet, on which the quality of the finished tubes entirely depends, is very largely a matter of the skill of the caster, particularly as to rate and temperature of pouring. The greater control in manipulation that is possible with the coke-fired pit furnace has kept this type in use for making brass shell castings, although tilting and electric furnaces have largely superseded it for the casting of slabs, strips and billets. Crucibles are usually of 100-300 lbs. capacity. The copper is melted under charcoal, the other constituents being added in the following order : salt, to flux the copper oxide; brass scrap, if any ; and finally the zinc. Constant stirring is necessary. The metal is raised to pouring temperature and then cast, the shells being lifted out as soon as they are solid. The formation of a thin layer of carbon between the face of the casting and the mould enables this operation to be readily accomplished. As soon as the shell is exposed to the air, the carbon burns off, leaving the shell quite clean. After cooling, the core bars are knocked out, and the sand is removed with a scraper and wire brush. A suitable casting temperature is about 1130-1150° C.

Except for certain lightly-stressed structural parts, sand-cast brass has only a small application in general engineering work. The usual type of casting is thus of very light section in comparison with its mass, necessitating the use of large gates well distributed. As solidification shrinkage is greater than in tin-bronzes, ample provision must be made for feeding. For small work, the greensand method is used, but, for larger work in the usual light section, the moulds should be skin-dried, because of the high pouring temperature necessary to avoid cold-shuts and mis-runs. This is particularly necessary in and near the gates, to prevent erosion and scabbing. When making brass castings from virgin metals, a cover of charcoal should be used. Common brass castings are often made from all-scrap charges, adding zinc to make up for oxidation loss. Here a cover should also be used, borax, giving a thin fluid slag, being generally employed for this purpose.

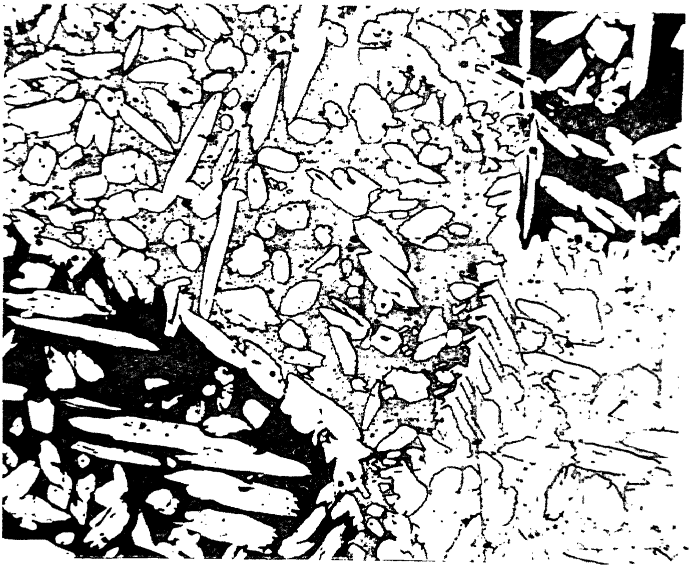
Manganese-Bronze and High-Tensile Brasses. These constitute an important series of alloys which have been developed from the ordinary brasses. They are made by replacing some of the zinc by manganese and iron, and sometimes by tin and aluminium, the range of composition laid down by the American Society for Testing Materials for manganese-bronze sand castings (A.S.T.M. Spec. No. B54-27) being as follows:

	Max.	*Min.*
Copper %	60	55
Zinc %	42	38
Tin %	1·5	0·0
Manganese %	3·5	0·0
Aluminium %	1·5	0·0
Iron %	2·0	0·0
Lead %	0·4	0·0

Higher proportions of aluminium, up to 4 or 5 per cent., are sometimes used. Such alloys are very much stronger than the straight brasses, a tensile strength even of 50 tons per sq. in. being obtainable. The A.S.T.M. specification in question demands 65,000 lb., or 29 tons per sq. in., as a minimum, with not less than 25 per cent. elongation before fracture, figures which are readily obtainable. The alloys of higher strength show a corresponding diminution in ductility, a tensile strength of 40 tons per sq. in. being usually associated with an elongation of 15-20 per cent.

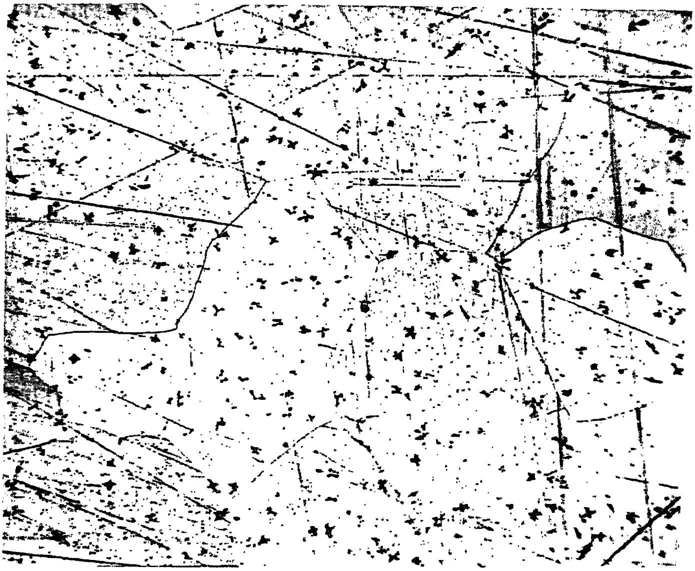
These alloys may be classified, as are the straight brasses, by micro-structure. In the straight brasses, the alloys cooled under normal foundry conditions, and containing up to about 37 per cent. of zinc, consist wholly of the pale yellow α-solid solution, those containing more than this proportion showing a second zinc-rich constituent, β, seen under the microscope as distinct reddish crystals, interspersed among those of the yellow α. The α brasses are soft and ductile, increasing both in strength and ductility as the zinc content increases, and are very suitable for cold-working. The presence of β, a stronger but less ductile constituent, increases the strength but reduces the ductility, while also conferring plasticity over a wide range of temperature, so that the $\alpha\beta$ brasses are very suitable for hot-working. Because of the greater strength of the β constituent, the $\alpha\beta$ and full β brasses are those comprising the high-tensile casting brasses in question. The other metals used often have an effect on the microstructure, resembling—and either more or less marked than—that of zinc, the " equivalence " of aluminium being greater, and those of iron and manganese less than that of zinc; while the physical properties can be improved considerably. The $\alpha\beta$ alloys are those in general use for casting purposes, a typical example being shown in Fig. 158, where the irregularly-shaped islands are those of the α-constituent, set in a darker background of β. On increasing the proportion of zinc or of the equivalent " hardening " constituents, the softer α gradually disappears, being replaced by a full β structure, as in Fig. 159. Here the large crystals are the β-constituent, the minute crystallites, frequently in star or rosette form, being the γ-constituent.

Moulding Practice. Compared with tin-bronzes, the manganese " bronzes " have a much greater liquid shrinkage and are more liable to the formation of oxide on the surface of the molten metal, being thus more difficult to cast sound. Except for very small castings, the moulds should be dried, the absence of moisture and the hard, strong and more per-



(*Micro. by J. R. Bryant*) (× 100)

FIG. 158.—MANGANESE ALUMINIUM BRASS, SHOWING α AND β CONSTITUENTS

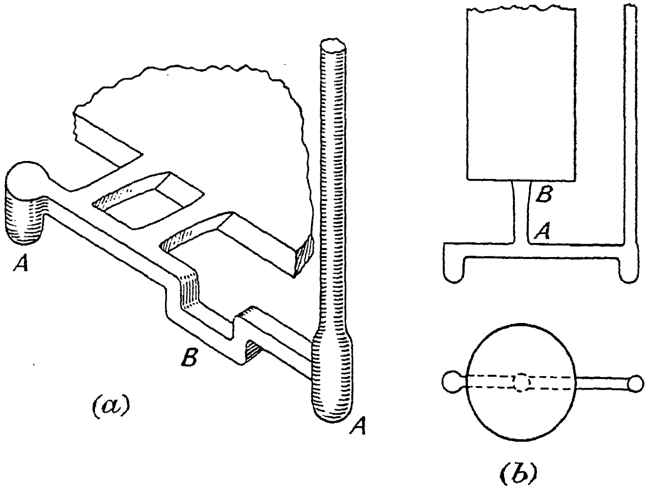


(*Micro. by J. R. Bryant*) (× 100)

FIG. 159.—BRASS, SHOWING β AND γ CONSTITUENTS

[*To face p.* 290

meable mould surface promoting the production of sound castings. The metal must flow quietly, with no disturbance as it rises in the mould, and solidification must be progressive from the parts more remote from the feeding gates or heads, to the feeders themselves. For these essential conditions, the runner gates must enter at or near to the bottom of the casting, and be so designed as to prevent any "jet-like" effect in the stream of metal leaving the gates. The need for fillets, and precautions in making these, have already been referred to (p. 280). Dross sumps and filters are desirable, but will be of little use unless the metal flows through them quietly. Fig. 160 (*a*) shows how these principles can be followed in making a shallow light casting.



AA—Dross Sumps *B—Dross Trap*

FIG. 160.—GATING FOR MANGANESE-BRONZE :—(*a*) METHOD OF GATING A SHALLOW CASTING; (*b*) METHOD OF GATING A DEEP CASTING

The gating of deep castings is illustrated in Fig. 160 (*b*). There must be a small gradual increase in the cross-sectional area of the gate from A to the entry at B. For large castings, a number of in-gates are required, all made in this manner, when turbulence is avoided, and a sound casting obtained. When bottom-gating, unless the place of entry is capable of being fed adequately from above, the casting may be drawn at this position. In gun-metal practice, such shrinkage would be avoided by means of large self-feeding runner gates. Because of the great tendency of manganese-bronze to produce dross, however, alternative remedies must be found, as in Fig. 161. Here the metal, entering the bottom of the feeder through a small runner gate, flows quietly on to fill the mould, any dross passing the runner floating up the feeder instead of getting into the casting.

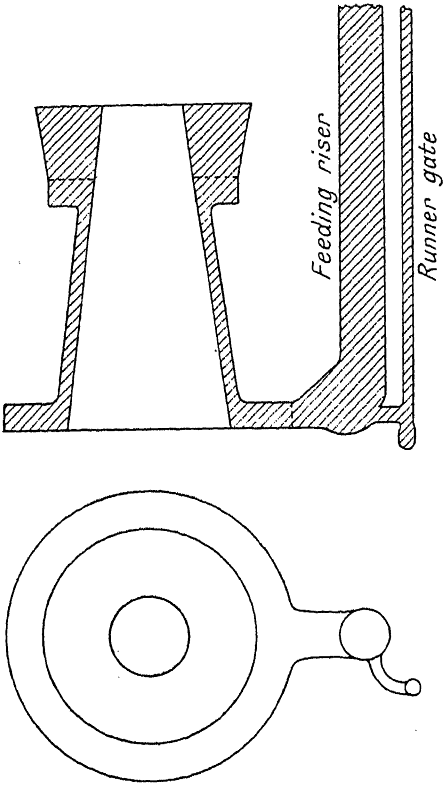


Fig. 161.—Special Method of Gating Manganese-Bronze

Feeding Heads. These must be used on all jobs which are deep or comparatively so. The size of head required depends primarily upon the design of the casting, a fairly shallow one being sufficient for the type shown in Fig. 161. For a short massive cylindrical casting about 10 or 12 in. long, and with a wall thickness of 2-3 in., one may have to use a head 1½ times the length of the casting. If the head is made more massive—either by splaying or by making it of bulbous shape—its solidification will be retarded, and its height can thus be usually reduced considerably. Its efficacy can also be improved by pouring hot metal directly into the head as soon as the mould is full, when, again, the height can be somewhat diminished. In this case, however, the lip of the ladle must be kept very near to the surface of the metal in the head, or oxide may be carried down by the stream into the casting. When possible, the job should be cast with the head open, and the behaviour of the metal in the mould observed during the process, this having obvious advantages in guiding future gating technique. Also, by using a rod, one can often manipulate small pieces of dross so that they are carried up into the head.

Chills are used extensively in manganese-bronze practice ; indeed, all heavy masses which cannot be fed by suitable heads or risers must be heavily chilled if the castings are to be sound. For chills, cast iron is suitable. Copper containing 1 per cent. of zinc gives better heat conductivity and may sometimes be preferable, but such chills used near to a runner gate may fuse on to the casting.

Pouring Temperature. If provision is made for solidification shrinkage, pouring temperature has little influence on density, an effect quite unlike that found with tin-bronzes. But too high a pouring temperature is undesirable, increasing the amount of dross, and leading to greater local heating of the mould near the gates, thus increasing shrinkage. The usual types of casting are poured at 950–1000° C., 950° for the more massive and heavier castings and 1000° for thinner and more intricate ones.

Melting Practice. Crucible furnaces are preferable to those of open-hearth type, permitting better control of zinc content, the amount of which largely controls the structure and mechanical properties of the alloy. When only a small quantity of metal is required, or, even for larger amounts, if it is intended to cast direct, without previous ingoting, the manganese and iron should be added as cupro-manganese and ferro-zinc, respectively. The crucible is heated and a layer of charcoal put in the bottom. On this are charged the constituents of high melting-point, the cupro-manganese and ferro-zinc, or the ferro-manganese or mild steel, if these are being used. The ingot copper is put on top, and the whole is melted as rapidly as possible. The aluminium is then added, and finally the zinc. When the desired temperature has been reached, the melt must be thoroughly stirred with an up-and-down motion, and skimmed clean before pouring. When ferro-manganese or mild steel have been used, one should ingot and re-melt before casting, adding extra zinc to cover the loss on the further melt.

Aluminium-Bronze. Because of their high corrosion-resistance, strength and ductility, the aluminium-copper alloys, or "aluminium-bronzes," are being increasingly used. The alloys generally used for castings contain from 8½ to 10 per cent. of aluminium, the remainder being copper. Specifications often call for small amounts of iron, and nickel is sometimes added, when much greater strength is obtainable. In all these alloys, the dross-forming tendency, the solidification shrinkage and the solid shrinkage are high. It is thus difficult to make good castings, a special technique being required. With general castings, the difficulty is to prevent the formation of oxide on the metal in the gates, and in the mould itself. The least agitation of the surface of the metal causes oxide to form, and, as with manganese-bronze, once formed, it is not re-absorbed into the metal, remaining as an inclusion.

Gating should be as for manganese-bronze, success being attained by ensuring a clean quiet stream of metal, of velocity and volume just sufficient to fill the mould without any chance of cold-shuts. Unless the design permits the region near the gate to be self-feeding from above, as with a billet run from the bottom, one should use a number of small gates, of about ⅛ to ¼ sq. in. in area. The size and number depends on the superficial area and wall thickness of the casting. Feeding heads and risers are also much as for manganese-bronze, but the higher solidification shrinkage demands larger feeders. These must be self-feeding, with solidification progressive from the casting to the mass in the upper part of the feeder.

Melting Practice. Any type of crucible furnace giving rapid melting is suitable. Iron or nickel should be put at the bottom on a layer of small pieces of charcoal; then the copper, the whole being melted as rapidly as possible. The aluminium is added last, as 50 : 50 aluminium-copper pig, made beforehand. The melt is brought as quickly as possible to the required temperature, thoroughly stirred and carefully skimmed before pouring.

Casting Temperature. This varies somewhat with composition and design, being usually between 1175° and 1200° C. The actual temperature is not very critical, but higher temperatures increase the dross-forming tendency and liquid shrinkage. One should use a temperature as low as will give a casting free from cold-shuts.

The Aluminium Alloys. The aluminium alloys, with their low density, only a little over one-third that of cast iron or gun-metal, have a large and increasing application, as for pistons, when a great reduction can be made in the weights of the moving parts. This advantage has led in turn to the development of stronger alloys for this purpose. The chief aluminium casting alloys are given in the following table, the test figures cited being those of the B.S.I. and D.T.D. Aircraft Specifications, so that the figures usually obtainable are somewhat higher.

The earliest alloys and the cheapest in general use are those containing copper and zinc, both of these acting as hardeners, reducing the ductility, increasing the resistance to abrasive wear and facilitating machining. As seen, many other elements are alloyed with aluminium, to produce alloys with special properties. L. 5 has considerable application, being cheap and strong, with reasonable ductility. The high zinc content makes it very hot-short over a comparatively long range of temperature below the freezing point, and it is most unsuitable for castings exposed to heat. Here the straight copper-aluminium alloys, as L. 11 and L. 8, are preferable, maintaining their strength much better at high temperatures. L. 8, although inferior to L. 11 in ductility,

ALUMINIUM CASTING ALLOYS

Description	Aluminium-Zinc-Copper Alloy Castings	12% Copper-Aluminium Alloy Castings	7/1 Aluminium Alloy Castings	Y-Aluminium Alloy Castings	Silicon-Aluminium Alloy Castings	Al. Alloy Sand or Die Castings (not suitable for pistons) —R.R.50	Al. Alloy Sand or Die Castings (suitable for pistons) —R.R.53
Specification	B.S.S. 3L.5	B.S.S. 3L.8	B.S.S. 4L.11	B.S.S. 2L.24	B.S.S. L.33	D.T.D. 133B	D.T.D. 238
Copper	2·5–3·0	11·0–13·0	6·0–8·0	3·5–4·5	—	0·8–2·0	1·5–2·5
Nickel %	—	—	—	1·8–2·3	—	0·8–1·75	0·5–2·0
Magnesium %	—	—	—	1·2–1·7	—	0·05–0·30	1·4–1·8
Manganese %	—	—	—	—	0·50 (max.)	—	—
Iron %	0·80 (max.)	0·80 (max.)	0·80 (max.)	0·60 (max.)	0·60 (max.)	0·8–1·40	1·2–1·5
Silicon %	0·70 (max.)	0·70 (max.)	0·70 (max.)	0·60 (max.)	10–13	1·5–2·80	2·0 (max.)
Iron plus silicon %	—	—	—	1·0 (max.)	—	—	—
Lead %	0·10 (max.)	0·10 (max.)	0·10 (max.)	0·05 (max.)	—	—	—
Titanium %	0·20 (max.)	0·20 (max.)	0·20 (max.)	0·20 (max.)	0·20 (max.)	0·05–0·25	0·02–0·12
Tin %	—	—	1·0 (max.) }	{ 0·10 }	—	—	—
Zinc %	12·5–14·5	0·10 (max.)	0·10 (max.) }	{ (max.) }	0·10 (max.)	—	—
Total other metallic constituents %	—	—	—	—	0·10 (max.)*	—	—
Total modifying agents (namely: sodium, tungsten, chromium, cobalt, boron and calcium) ..	—	—	—	—	0·30 (max.)	—	—
Aluminium %	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.
Min. results (as-cast state), on bar cast in:	Dry-sand mould	Dry-sand mould	Chill mould	Dry-sand mould	Dry-sand mould	Dry-sand mould	Dry-sand mould
Ult. St., T. □″	9	7	7·5	10	10·5	11	9
Elongation %	2	—	1·5	—	5	2·5	—

---

* Excluding those used as modifying agents.

is superior in this respect, and was formerly used for a large proportion of automobile pistons, Y-alloy competing later with L. 8 for this duty. Heat treatment of both these alloys is desirable, Y-alloy being then much improved, so that tensile strengths of 20 tons per sq. in., and higher, are obtainable. Still more recently, many other alloys have been developed, some of still higher temperature-resisting quality, so that the straight copper-aluminium alloys are being largely replaced for this duty. The R.R. alloys cover a wide range of composition, and may be regarded as derivatives from Y-alloy. R.R.50 is easy to cast, has good strength without requiring heat treatment, and is thus used for highly-stressed crank-cases, cylinder blocks, cylinder heads and other large and complicated castings where the process of heat treatment might set up severe internal stresses by reason of the varying section. R.R.53, used considerably for die-cast pistons, is specially suitable for use at elevated temperatures, either in the as-cast state, or heat-treated, when strengths of 23-25 tons per sq. in., with about 1 per cent. elongation, are obtainable, so that considerable reductions in inertia loads are possible, the heat-treated alloy being naturally more advantageous in this respect. For resistance to corrosion, as by sea water, the silicon-aluminium alloy is the best, being thus often preferred for use on board ship. Its properties when cast without special procedure are markedly inferior to those obtainable by the process of "modification" referred to later.

Aluminium Founding. There is no reason why any good moulder of iron or brass should not have equal success with aluminium, but certain precautions must be observed. The high solidification shrinkage of this metal makes it necessary to apply chills or risers to all heavy masses. When a boss, or other part of heavy section, is near to the top of the casting, one should use, direct on to the boss, a feeding riser as large as or even larger than the part to be fed. Risers are often used on the high parts of a casting, to allow the escape of air; for, owing to the lightness and low casting temperature of the metal, a comparatively low air-pressure inside the mould will often cause a casting to be short-run, if and heavy sections, the mould at the lighter sections being heated to a higher temperature, so as to prolong the period of solidification, while the metal of the heavier sections has run further through a cooler mould, so that its solidifying period is shortened. It is generally desirable so to design the in-gate that the metal contained in it will freeze later than the metal of that portion of the casting which immediately adjoins the gate. A method of ensuring this is shown in Fig. 162. The narrow neck of sand at T very quickly reaches a high temperature, and has therefore little or no cooling effect; while solidification is prolonged at S, so that metal can feed from the runner R to the casting U. The heating of the sand round the gate also tends to retard solidification in the runner, thus facilitating feeding. All runner gates should be so designed as to permit the metal to enter the mould as quietly as possible, and running at or near the bottom is therefore more successful. An exception to this general statement is involved in the running of deep castings, where the necessarily low pouring temperature makes it difficult, by this method of running, to force the metal up to the top of the mould, so that top-pouring must be resorted to. The pencil-runner described on page 134 is also employed occasionally on jobs which are difficult to run successfully by other methods, the aim being to allow the metal to freeze as soon as it has taken up its permanent position in the mould. Higher pouring temperatures have to be adopted, and risers and chills can usually be dispensed with.

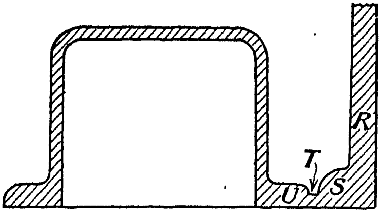


Fig. 162.—Runner designed to avoid Shrinkage Cavity in Flange

Melting Appliances. The melting of aluminium alloys is generally done in plumbago crucibles, iron pots or reverberatory furnaces, lined with firebrick. The first method is the most expensive, not only on account of the high cost and short life of the crucibles, but also because their low heat conductivity necessitates a greater fuel consumption. It is chiefly used for special work, where even very slight contamination may be undesirable. A good deal of aluminium is melted in cast iron pots, where, to prevent iron getting into the melt, an inside coating with a wash of whitening and plumbago is given. These are usually shaped like a washing boiler, and are seated in a firebrick casing, being heated either by gas or fuel oil. Oil firing is much more economical, the burner being fitted to blow in near to the bottom of the pot, so that the products of combustion enter at a tangent, and circle round the pot before passing to atmosphere. The objection to reverberatory furnaces is that the flames come into contact with the metal, and, owing to the extremely rapid rate of melting, great care is necessary to avoid overheating, the production of excessive dross, and greater metal losses, in addition to a considerably greater likelihood of the metal being permanently deteriorated from this cause. On the other hand, reverberatory furnaces are economical in fuel and maintenance, the firebrick lining lasting a long time and being then readily replaced.

Alloying and Melting for Aluminium. Owing to their manifold advantages, an enormous number of different aluminium alloys are used in industrial practice, but cannot be discussed here. A brief account of the alloying and melting of a few of the more common ones should, however, be useful. Several of these, as L. 5, L. 8 and L. 11, contain copper. Because of the high melting point of copper (1083° C.) as compared with aluminium (650° C.), it is better to melt first a known weight of copper, and then to add aluminium, a little at a time, until the mixture consists of 50 : 50 alloy, which is then stirred thoroughly and poured into chill moulds. The 50 : 50 alloy can then be added direct to the melt to give the correct percentage of copper. Zinc can be added direct, but, owing to its low melting point (419° C.), it should be put in last, the metal being afterwards stirred gently before pouring. For L. 5 Alloy, where the specified proportion is from 12·5 to 14·5 per cent. of zinc, the addition of about 16 per cent., to make up for the loss by volatilisation, will be found approximately correct. For the copper-zinc alloys, it is not advisable to exceed a melting temperature of about 750° C. Aluminium readily absorbs gases as the temperature rises, time also playing an important part in these reactions, so that both a high temperature and stewing should be avoided. A melting temperature of 800° C. may often be reached without serious consequences, providing the metal is not stewed, and if it is cooled to the correct casting temperature before pouring. But the effects of high-temperature heating may not be corrected by allowing to cool to the correct temperature, the castings containing pinholes, being porous, and showing a greater tendency to be drawn or cracked. The colour may also be dull, the castings sometimes exhibiting brown stains where the metal enters from the runner. The effects of high-temperature heating, however, are not always apparent to the eye, while the strength and elongation figures also may be quite good. But the resistance to shock may be considerably diminished, which in many types of casting may lead to serious consequences. As a good practical guide, a correct pouring temperature is that which just gives the fluidity necessary to fill the mould, and results in the production of a bright silvery finish on the castings as they leave the mould. The most suitable temperature varies somewhat with the alloy being used, and also with the type of casting, 700° C. being about correct for a large variety of castings, the use of an immersion pyrometer being of course essential on high-class work.

The silicon-aluminium alloys can be made either by melting together commercially pure aluminium and silicon, or a 20 per cent. silicon-aluminium hardener may be used. These alloys are much improved by treatment, before pouring, by a patented process known as "modification," and involving the use of a mixture of sodium chloride and fluoride, of commercial caustic soda, or of metallic sodium. After modifying at about 760° C., the metal is allowed to stand about 2½ minutes, stirred quietly, and poured. By this treatment, the particles of silicon become finer and more dispersed, and the strength and elongation are considerably increased. Melting for Y-alloy and many of the special alloys is a little difficult and complicated, so that it cannot adequately be dealt with here. That for Y-alloy is given on p. 33 of the Eleventh Report to the Alloys Research Committee. It will be appreciated that this chapter is somewhat curtailed, but, as has already been pointed out, ferrous and non-ferrous foundry practice have much in common. An attempt has been made, however, to cover the essentially different technique required in the production of the more important non-ferrous alloys.

APPENDIX: CONTRACTION OF CASTINGS

The usual allowances by which the dimensions shown on the drawing must be increased by the pattern-maker, in order that the dimensions of the casting shall be those required, are as follows :—

Aluminium Alloys :	*Per Foot*
B.S.I. 3 L 5	$\frac{5}{32}$ in.
B.S.I. 3 L 8	$\frac{5}{32}$ in.
B.S.I. 4 L 11	$\frac{9}{64}$ in.
B.S.I. 2 L 24 (Y-alloy)	$\frac{5}{32}$ in.
B.S.I. L 33 (Wilmil, Alpax or Silumin)	$\frac{5}{32}$ in.
Aluminium Bronze	$\frac{1}{4}$ in.
Bismuth	$\frac{5}{32}$ in.
Brass, yellow (thick)	$\frac{5}{32}$ in.
,, ,, (thin)	$\frac{3}{16}$ in.
Cast Iron, grey	$\frac{1}{10}$ to $\frac{5}{32}$ in.

(The amount of contraction depends primarily upon the speed with which the casting cools, more rapid cooling leading to greater contraction, and vice versa. Large hollow castings contract less in a vertical than in a horizontal direction.)

Cast Iron, white	$\frac{1}{4}$ in.
Delta Bronze	$\frac{3}{16}$ in.
Gun-metal	$\frac{1}{8}$ to $\frac{3}{16}$ in.
Lead	$\frac{5}{16}$ in.
Magnesium	$\frac{1}{4}$ in.

Magnesium Alloys (5 per cent., or over, of alloys, excluding cadmium, which has no effect on the shrinkage of magnesium)	$\frac{3}{16}$ in.
Manganese-Bronze	$\frac{1}{4}$ in.
Monel Metal	$\frac{1}{4}$ in.
Nickel	$\frac{1}{4}$ in.
Phosphor-Bronze	$\frac{1}{8}$ to $\frac{3}{16}$ in.
Steel	$\frac{3}{16}$ to $\frac{1}{4}$ in.
Steel, chromium	$\frac{1}{4}$ in.
Steel, manganese	$\frac{5}{16}$ in.
Stone's Gear-wheel Bronze	$\frac{1}{8}$ in.
Tin	$\frac{1}{4}$ in.
Zinc	$\frac{5}{16}$ in.

INDEX

INDEX

Where there are references to more than one page, numerals in black-faced type denote those which are more important.

ACME Vertical Core-Drying Stove, 52
Aluminium—
  Alloying, 301
  Casting Temperatures, 302
  Chills, 299
  Cores, 298
  Founding, 297
  Melting, 301
  Melting Appliances, 300
  Moulds, 298
  Runner Gates, 299
Aluminium Alloys, 295
Aluminium-Bronze, 294
Annealing—
  For Blackheart Malleable, 274
  For Stress Release, 151
  For Whiteheart Malleable, 272
August-Bormann Core-Blowing Machine, 43
Austenitic Cast Irons, 200

B.M.C. 240 Improved Sand Rubbing Machine, 17
Balanced-Blast Cupola, 255
Bed—
  Permanent, 30
  Preparation of, 30
Bedding-in, 71
Blackheart Malleable, 273
Blacking, 34
Blowholes, 22, 28, 41, **61**, **141**, **283**, 298
Brackelsberg Furnace, 262
Brads, 62
Brass Casting, 288
Brasses, Complex, 289
Brasses, High-Tensile, 289
Bronze—
  Casting, 278
  Casting Temperatures for, 284
Building (in Loam Moulding), 162

CALCULATIONS for Compositions, 225
Cambering, 148
Carbon Control in Cupola, 247
Cast Iron—
  Austenitic, 200
  Changes after Solidification, 217
  Changes effected by Cupola Melting, 225
  Chilled, 266
  Composition for Chilled Rolls, 269
  Composition in Relation to Solidification Shrinkage, **147**, 194
  Compositions for Various Purposes, 225
  Condition of Carbon in, 183
  Constitutional Diagram, 185
  Contraction in—see under *Shrinkage*
  Cooling of, 185
  Density of, 215
  Desulphurisation of, **196**, 249
  Effect of Carbon, 193
  Effect of Chill-Casting, 266
  Effect of Chromium, 202
  Effect of Different Constituents, 193
  Effect of Manganese, **196**, **198**
  Effect of Nickel, 198
  Effect of Nickel and Chromium together, 202
  Effect of Phosphorus, **197**, 224
  Effect of Silicon, 185, **194**
  Effect of Special Elements, 198
  Effect of Sulphur, 196
  Graphitisation in, **183**, **190**, 206, 210, **212**, **216**, **271**
  Graphitisation in Malleable C.I., 271
  Grey, 188
  Growth of, 208
  Heat Treatment of, 207
  High-Duty, 203
  Inoculated, 205, **210**
  Latent Heat of Fusion of, 260
  Malleable, 270
  Martensitic, 199
  Melting of, 240
  Metallurgy of, 183
  Over-chilling, 146
  "Pearlitic," 204
  Relation of Charge and Final Carbon, 194

- Cast Iron—
  - Relation of Combined Carbon and Tensile Strength, 194
  - Relation of Graphitic Carbon and Tensile Strength, 194
  - Relation of Tensile and Transverse Strength, 221
  - Relation of Total and Graphitic Carbon, 188
  - Relation of Total Carbon and Tensile Strength, 194
  - " Semi-Steel," 203
  - Shrinkage in—see under *Shrinkage*
  - Solubility of Carbon in, 185
  - Specific Heat of, 260
  - Superheating of, **212**, 249
  - Tensile and Transverse Test Requirements, 219
  - Testing, 219
    - Brinell Test, 223
    - Chill Test, **237**, **269**
    - Fluidity Test, 235
    - Foundry Control Tests, 235
    - Fracture Test, 239
    - Hardness Tests, 223
    - K-Test Bar, 236
    - Keep's Test, 237
    - Liquid Shrinkage Tests, 236
    - Solid Contraction Test, 237
    - Tensile Strength, 220
    - Transverse Strength, 219
  - White, 187
- Casting of Non-Ferrous Alloys, 277
  - Aluminium Alloys, 295
  - Aluminium-Bronze, 294
  - Brass, ordinary, 288
  - Brass, high-tensile, 289
  - Bronzes, 278
  - Gun-Metal, 278
  - Manganese-Bronze, 289
  - Phosphor-Bronze, 286
- Castings, Defects in—
  - Blowholes in, 22, 28, 41, **61**, **141**, **283**, 298
  - Cracked, 28, **151**, 164, 298, 302
  - Leaky through chaplets, 60
  - Piping in, 140
  - Rough Surface on, 21
  - Scabbed, 6, 22, 28, **120**, 122, 298
  - Shrinkage Cavities in, **140**, **147**, 151, **218**, 283, 302
  - Warped, **148**, 151
- Centres—
  - Fixed, 158
  - Portable, 157
- Centrifugal Sand Mixer, 15
- Chaplets, 60
- Chilean Mill, **17**, 18, 20
- Chill-Casting, 266
- Chill-Casting, Tests for, 269
- Chill-Castings, 266
- Chilled Rolls, 267
  - Casting of, 267
  - Dressing of Chills for, 268
  - Metal for Chills, 270
  - Metal for Rolls, 269
  - Tests for Chill-Casting, 269
- " Chills " (Denseners), **143**, 266, 287, 293, 299
- Chromium Cast Irons, 201
- Cinder Bed, 124
- Cinders, 34
- Closing, 73
- Coke, **254**, 260
- Composition in Relation to Solidification Shrinkage, **147**, 194
- Constitutional Diagram for—
  - Copper-Tin Alloys, 285
  - Iron-Carbon Alloys, 185
- Continuous Drying Stoves, 51
- Contraction—
  - Care of, 164
  - Keep's Test for, 237
  - Pattern-Maker's Allowance for, 96, **147**, 215, **237**, **303**
  - Solid, 96, **147**, 215, **237**, **303**
  - Stresses due to, 148
- Cope, Drawing down of, 174
- Copper-Aluminium Alloys, 294
- Copper-Tin Constitutional Diagram, 285
- Core, Definition of, 26
- Core Barrels, 38
- Core Binders, 18, **40**
- Core-Blowing Machines, 43
- Core Boxes, 29
- Core Cradles, 41
- Core Drying, 48
- Core-Iron Clearance, 30
- Core-Irons, **30**, 36
- Core Loams, 18
- Core-Maker's Tools, 35
- Core-Making, 26
- Core-Making Machines, 42
- Core-Making, Principles of, 1
- Core Plates, 32
- Core Prints, 26
- Core Registers, 45
- Core Sands, 18
- Core Stoves, 49
- Core Venting, 46
- Cores—
  - Advantages of, 27
  - Barrel, 38
  - Chill, 28
  - Dry-Sand, 28, **36**
  - For Aluminium, 298
  - Greensand, 28
  - Loam, 28, **37**
  - Manufacture of, 35

Cores—
  Moulding in, 92
  Oil-Sand, **19**, **40**
  Patterns leaving Own, 29
  Securing of, 44
  Types of, 28
  Uses of, 27
Cracked Castings, 28, **151**, 164, 298, 302
" Crossing," 149
Crucible Furnace, 265, **281**, 300
Cupola Furnace, 240
  Air Supply, 250
  Arrangement, 240
  Balanced-Blast, 255
  Bed, 249
  Blast Pipe, 243
  Blast Pressure, 252
  Blast Volume, 247, **250**
  Blowing-down, 247
  Blowing Machines, 251
  Bott-Clay, 246
  " Botting-up," 246
  Carbon Control in, 247
  Carbon Pick-up in, **194**, **247**
  Changes in Melting in, 225
  Charge Preheating, 241
  Charging, 244
  Coke, **254**, 260
  Control of Working, 252
  Design, 240
  Drawing of Slag, 247
  Drop-Bottom, 240
  Duplex Process, 249
  Fans, 251
  Fixed-Bottom, 241
  Flux, 8, 245, **255**
  Fore-Hearth, 242, **248**, 249
  Gases, **249**, 260, 261
  Melting Changes in, 225
  Melting Costs, 257
  Melting Rate, 240
  Melting Zone, 243
  Miscellaneous Data, 259
  Poumay, 255
  Preparation of, 243
  Reactions, 249
  Repairing, 244
  Slags, 255
  Tap-Hole, 244
  Tuyeres, 242
  Volume Gauge, 251
  Well, 242
  Windbelt, 243
Cupolas, Special, 255
Cylinder Mixture, **220**, **231**

D.A.K.N. Squeezer Core-Making Machine, 42
Defects in Castings—see *Castings*
Denseners (or Chills), **143**, 266, 287, 293, 299
Design as a Factor in Production, 151
Desulphurisation of Cast Iron, **196**, 249
" Down Sand Frame " Method, 105
Drawbacks, 72
" Draws "—see *Shrinkage*
Dressing of Chills for Rolls, 268
Dry-Sand Mixing, 17
Dry-Sand Mixtures, 16
Dry-Sand Moulding, 16
Dry-Sand Moulds –
  Drying of, 123
  Testing of, 123
Drying Stoves, Continuous, 51
Drying Stoves, Design of, 49
Drying Temperatures, 49
Duplex Foundry Sand Mixer, 15
Duplex Process, 249

EASING-BARS, 166
Edge-Runner Mill, **17**, 18, 20
Elutriation, 20

FACE-SPRIGGING, 125
Feeding Heads, **141**, 278, 289, 291, 294, 297 (see also *Risers*)
Finishing, 73
Fluxes for Iron Melting, 8, 245, **255**
Fluxes for Non-Ferrous Melting, **282**, 288, 302.
Flywheel Mixture, 232
Foundry Control Tests, 235
Foundry Lay-Out (Repetition), 116
Foundry Pig Irons, 224
Foundry Mixtures, 225
French Chalk, **35**, 298
Funnel for Nickel Additions, 201
Furnaces for Iron Melting, 240
  Brackelsberg, 262
  Crucible, 265
  Cupola, 240
  Oil-Fired Rotary, 264
  Reverberatory, 261
  Rotary, 262
  Sesci, 263
Furnaces for Non-Ferrous Melting—
  Crucible, **281**, 300
  Electric, 281, 288
  For Aluminium, 300
  For Brass, 288
  Reverberatory, **281**, 293, 300

GAGGERS, 58
Gating, **127**, 278 (see also *Runners and Runner Gates*)

- Graphite—
  - Effect of Gases on, 212
  - Effect of Non-Metallic Inclusions on, 212
  - Effect of "Silicate Cloud" on, 214
  - Effect on Tensile Strength, 190, **194**
  - Expansion caused by Separation of, 216
  - in Blackheart Malleable, 273
  - in High-Duty Irons, 204
  - in Lanz Perlit Iron, 206
  - in Malleable Cast Iron, 271
  - in Meehanite Iron, 211
  - in Ni-Tensyl Iron, 211
  - in Pig Irons, 183
  - in Thyssen-Emmel Iron, 210
  - in Whiteheart Malleable, 272
  - "Kish," 191
  - Primary, 191
  - Refinement by Desulphurisation, 196
  - Refinement by Superheating, **212**, 249
  - Relation to Total Carbon, 188
  - Secondary, 191
  - Separation during Cooling, **185**, **216**
  - Variation in Type of, 190
  - Variation with Rate of Cooling, 192
- Graphitisation—see *Graphite*
- Greensand Mixing, 15
- Greensand Mixtures, 13
- Greensand Moulding, 13
- Gun-Metal—
  - Blowholes in, 283
  - Casting Temperatures for, 284
  - Cooling Curves for, 285
  - Defects in, 283
  - Effect of Casting Temperature, 283
  - Fractures of, 283
  - Gases in, 283
  - Gating for, 278
  - Limits of Impurities in, 286
  - Mechanical Quality of, 286
  - Melting of, 281
  - Mould Dressings for, 280
  - Shrinkage (Incipient) in, 283
  - Shrinkage (Massive) in, 278, **283**
  - Structure of, 285
  - Use of Fluxes for, 282

- HANDLING Problems, 118
- Hardness Tests, 223
- High-Duty Irons, 203
- High-Tensile Brass, 289
- Holding-down, 153

- INOCULATED Cast Irons, 205, **210**
- Iron-Carbon Constitutional Diagram, 185

- JOINTS, 63
- Jolt- or Jar-Ramming, 107

- KEEP'S Test for Shrinkage, 237
- "Kish," 191

- L5 Alloy, 295
- L8 Alloy, 295
- L11 Alloy, 295
- Lanz Perlit Iron, 190, 195, **205**, 210, 222
- Lifters, 58
- Lifting Staples, 31
- Lifting Stress, 153
- Liner Mixture, 230
- Loam Core from a Pin-Board, 37
- Loam Mixtures, 18
- Loam Moulding, 17, **156**
  - Appliances for carrying Strickle Boards, 157
  - Bricks, 165
  - Building, 162
  - Building Loam, 156
  - Facing Loam, 156
  - Guides, 180
  - Plates, 161
  - Preventing Lateral Strain in, 167
  - Production Methods, 169
  - Runner Bushes, 138
  - Strickle Boards, Arms and Size-Sticks, 159
- Loose Pieces, 65

- MACHINE Foundry Lay-Out, 116
- Machine Moulding, 102
- Malleable Cast Iron, 270
  - Blackheart Process, 273
    - Annealing for, 274
    - Comparison with Whiteheart, 275
    - Composition for, 274
    - Test Requirements for, 275
  - Whiteheart Process, 271
    - Annealing for, 272
    - Comparison with Blackheart, 275
    - Composition for, 271
    - Test Requirements for, 273
- Manganese-Bronze, 289
- Martensitic Cast Irons, 199
- Meehanite Iron, 205, **210**
- Melting Costs for Cupola, 257
- Melting Costs for Different Units, 259
- Melting of Cast Iron, 240
- Melting of Gun-Metals, 281
- "Mending-up," 73

Metallurgy of Cast Iron, 183
"Modification," 302
Mould Dressings, **34**, 280, 288, 298
Mould Strain, 121
Moulder's Appliances, 62
Moulder's Tools, 36
Moulding and Running in relation to Design, 119
Moulding Boxes, 53
  Bolting, Cottering and Clamping, 57
  Jigs and Drilling, 57
  Methods of Location, 55
  Snap Flasks, 58
Moulding in Cores, 92
Moulding Machine Lay-Out, **113**
Moulding Machines, 102
  Jolt-Ram, 109
  Jolt-Ram Pattern-Draw, 110
  Jolt-Ram Turn-Over Pattern-Draw, 110
  Jolt-Squeeze, 109
  Pattern-Draw, hand-operated, 103
  Pattern-Draw, hydraulic, 104
  Pattern Mounting for, 102
  Sand-Slinger, 110
  Squeezer, hydraulic, 105
  Squeezer, magnetic, 107
  Squeezer, pneumatic, 104
Moulding, Principles of, 1
Moulding Sands, 1
  " Burning " of, 5, 6
  Choice of, 12
  Compositions of, 7
  Drying of, 4
  Effects of Clays, 9
  Effects of Impurities, 6
  Effects of Lime, 10
  Effects of Magnesia, 10
  Effects of Oxides of Iron, 9
  Effects of Potash, 10
  Effects of Silica, 8
  Effects of Soda, 10
  For Non-Ferrous Work, **20**, **277**
  Natural, 7
  Property of Adhesiveness, 3
  Property of Bond, 3
  Property of Durability, 6
  Property of Fineness, 2
  Property of Permeability, 5
  Property of Plasticity, 2
  Property of Refractoriness, 6
  Property of Strength, 3
  Testing of Bond, 24
  Testing of, Chemical Analysis, 24
  Testing of, Grain Size, 22
  Testing of, Moisture, 22
  Testing of Permeability, 23
  Use of Blackings, 11
  Use of Chopped Straw, 10
  Use of Coal Dust, 10
Moulding Sands—
  Use of Crude Oils, 11
  Use of Hops, 10
  Use of Horse Manure, 10
  Use of Oil-Sand, **19**, **40**
  Use of Sawdust, 10
Moulding Tackle, 53
Moulding Technique, 63

NI-TENSYL Cast Iron, 205, **210**
Nickel Cast Irons, 198
Nickel-Chrome Cast Irons, 202
Non-Ferrous Founding, 277

ODD-SIDES, 64
Oil-Fired Rotary Furnaces, 264
Oil-Sand, **19**, **40**
Open-Sand Plates, 32
" Over-Chilling," 146

PATTERN-MAKER'S Allowance for Contraction, 96, **147**, 215, **237**, **303**
Pattern Mounting for Machines, 102
Pattern Plates—
  Materials for, 97
  Plaster and Metal, 98
  Production of Metal Do. (Double-sided), 96
  Wooden, 99
Patterns—
  Distinguishing Colours on, 67
  For Plate Moulding, 94
  Mounting Split Do., 94
  Split, 68
" Pearlitic " Cast Irons, 204
Perlit Iron, 190, 195, **205**, 210, 222
Phosphor-Bronze Casting, 277, 285, **286**
Pig Irons, Grading of, 183
Pig Irons, Typical Foundry, 224
Pipe Chaplets, 61
Pipe Nails, 61
Piping, 140
Plaster of Paris, Use of, 65, 98
Plate Moulding, 94
  Patterns, for, 94
Plumbago, **34**, 280, 298
Poumay Cupola, 255
Pouring Temperatures for—
  Aluminium Alloys, 302
  Aluminium-Bronze, 295
  Brass, 288
  Bronzes, Various, 285

Pouring Temperatures for—
- Chilled Rolls, 270
- Gun-Metal, 281, **284**
- Lead-Bronze, 285
- Manganese-Bronze, 293
- Phosphor-Bronze, 285, **287**

Production of—
- Centrifugal Pump Casing, 91
- Chilled Roll, 267
- Condenser End Cover from Skeleton Pattern, 88
- Cover for Diesel Engine Manifold, 96
- Cylinder Liner for Diesel Engine, 75
- Flywheel, 169
- Loam Moulding (simple), 169
- Metal Pattern Plate (double-sided), 96
- Motor Base, 175
- Sluice Valve Cover, 78
- Do. from Split Pattern, 83
- Various Types of Casting, 75

Production, Special Methods of, 266
Pump Mixture, 233

RAMMERS, **59**, 167
Ramming, **119**, 277
Repairing, 73
Reverberatory Furnace, 261
Riser Plugs, 136
Risers, 127, **135**, 174, 278, 287, 291, 294, 297
- Dummy, 136
- Plugging of, **136**, 174
- Whistlers, 136
- See also *Feeding Heads*

" Rising off the casting," 136
Rod-Feeding, 142
Rolls, Chilled, 267
Rotary Furnaces, 262
Rotoil Sand Mixer, 20
Royer Sand Mixer and Aerator, 15
Runner Bushes, 137
Runner Core, 125
Runner Plugs, 139
Runner Stoppers, 139
Runners and Runner Gates—
- Dross Sumps, 291
- Dross Traps, 291
- Filter Runners, 134
- For Aluminium, 299
- For Aluminium Bronze, 294
- For Brass, 289
- For Gun-Metal, 278
- For Malleable Cast Iron, 268
- For Manganese-Bronze, 291
- For Phosphor-Bronze, 286
- Fountain Runners, 132
- Horn-Gates, 132
- Pencil-Runner, **134**, 300
- Position of Gates, 127
- Round Gates, 128
- Size of Gates, 127
- Spinner-Gate, **134**, 268
- Spray-Gates, 129
- Tangential In-Gate, **131**, 268
- Top-Gates, 128
- Top Trench, 133
- Trap-Runner, 135
- Types of Gate, 128

SAND MIXERS—
- B.M.C. 240 Improved Sand Rubbing Machine, 17
- Chilean Mill, 17
- Duplex Foundry Sand Mixer, 15
- Edge-Runner Mill, 17
- General, 115
- Rotoil Sand Mixer, 20
- Royer Sand Mixer and Aerator, 15
- Simpson Intensive Mixer, 17

Sand Preparation, **15**, **113**
Sand Testing, 21
Sands—see *Moulding Sands*
Scabbing, Causes of 6, 22, 28, **120**, 122, 298
" Semi-Steel," 203
Sesci Furnace, 263
Shrinkage, 96, 127, 134, 136, **140**, 143, **147**, 151, 194, 196, 198, 210, **214**, **218**, **236**, 278, 283, 287, 289, 290, 294, 297, **303**
- Cavities, 140
- Compensation by Chills, **143**, 299
- Compensation by Risers, **136**, **141**, 143
- Composition in Relation to, **147**, 194, 237
- During Cooling of Iron, 214
- Effect of Composition on, **147**, 194, 237
- Effect of Design on, 151
- Effect of Manganese on, 198
- Effect of Sulphur on, 196
- Effects, **140**, **218**
- in Aluminium Alloys, 297
- in Aluminium-Bronze, 294
- in Brass, 289
- in Gun-Metal, 278, **283**
- in Manganese-Bronze, 290
- in Phosphor-Bronze, 287
- in Production of Castings, 218
- in Thyssen-Emmel Iron, 210
- Keep's Test for, 237
- Pattern-Maker's Allowance for, 96, **147**, 215, **237**, **303**

Shrinkage—
  Piping, 140
  Stresses due to, 148
  Tests for, 236
  Use of Denseners to prevent, **143**, 299
  Use of Risers to prevent, **136**, 141, 143
Silicon-Aluminium Alloys, 302
Simpson Intensive Sand Mixer, 17
Size-Sticks, 159
Snap-Flasks, 58
Soapstone, 35
Soft Mixture, 234
Spigot and Socket Register, 173
Split Patterns, 68
Sprigging, 125
Sprigs, 62
Stack Moulding, 93
Staples, Sizes of Lifting Do., 31
Steatite, 35
Steels, 186
Stopping-off, 70
Stoves, 49
Straight Irons, 58
Strickle Boards, 156, **159**, 175
  Arms, 159
  Appliances for carrying Do., 157
  Centres for, 157
  For Flywheel Casting, 169
  For Loam Core, 37
  For Motor Base Casting, 175
  For Sand Work, 86
  Method of Attaching, 160
Strickle Boards—
  Size-Sticks, 159
  Use of, 159
Stripping Plates, 99
Superheating Cast Iron, **212**, 249

TALC, 35
Terra-Flake, **35**, 280, 298
Thicknessing Moulds, 90
Three-Part Jobs, 70
Thyssen-Emmel Iron, 209
Tools of Moulder and Core-Maker, 35
Turn-over Boards, 63

VENT Wires, 60
Venting, 5, **33**, 36, 40, **46**, 60, 79, **122**, 163, 277
Venting Materials, 33

WARPING, 148
Wax Vent, 34
Weighting-down, 153
Whiteheart Malleable, 271
Wood Screws, 61

Y-ALLOY, **296**, 303

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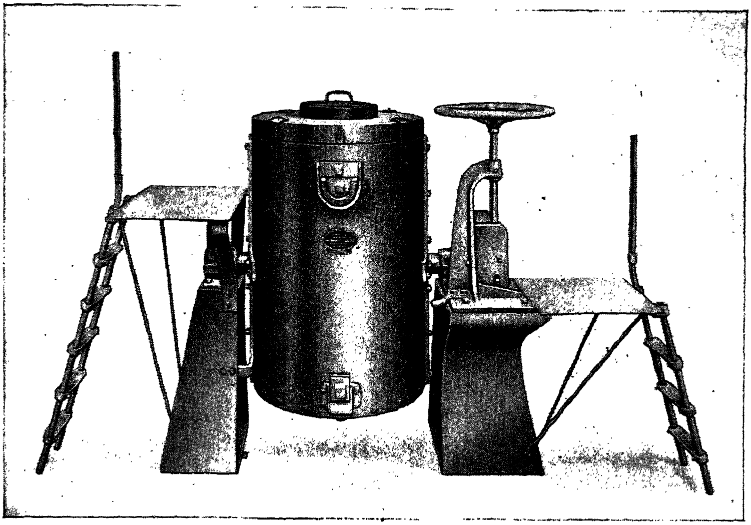

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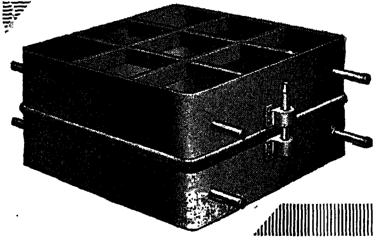

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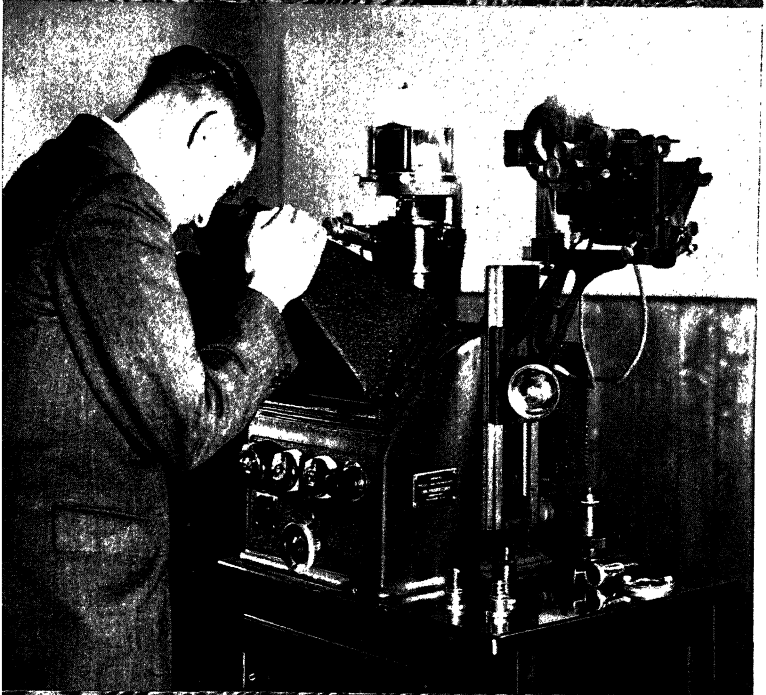

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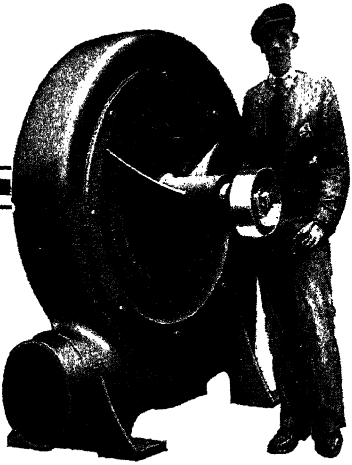

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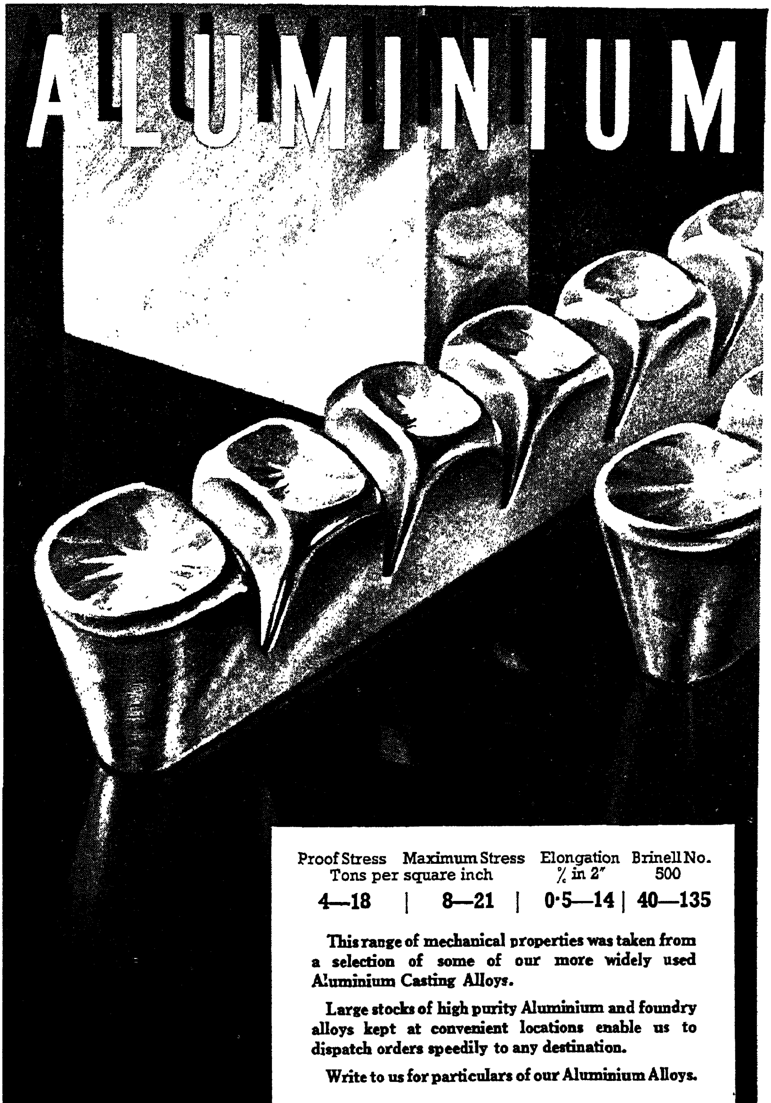

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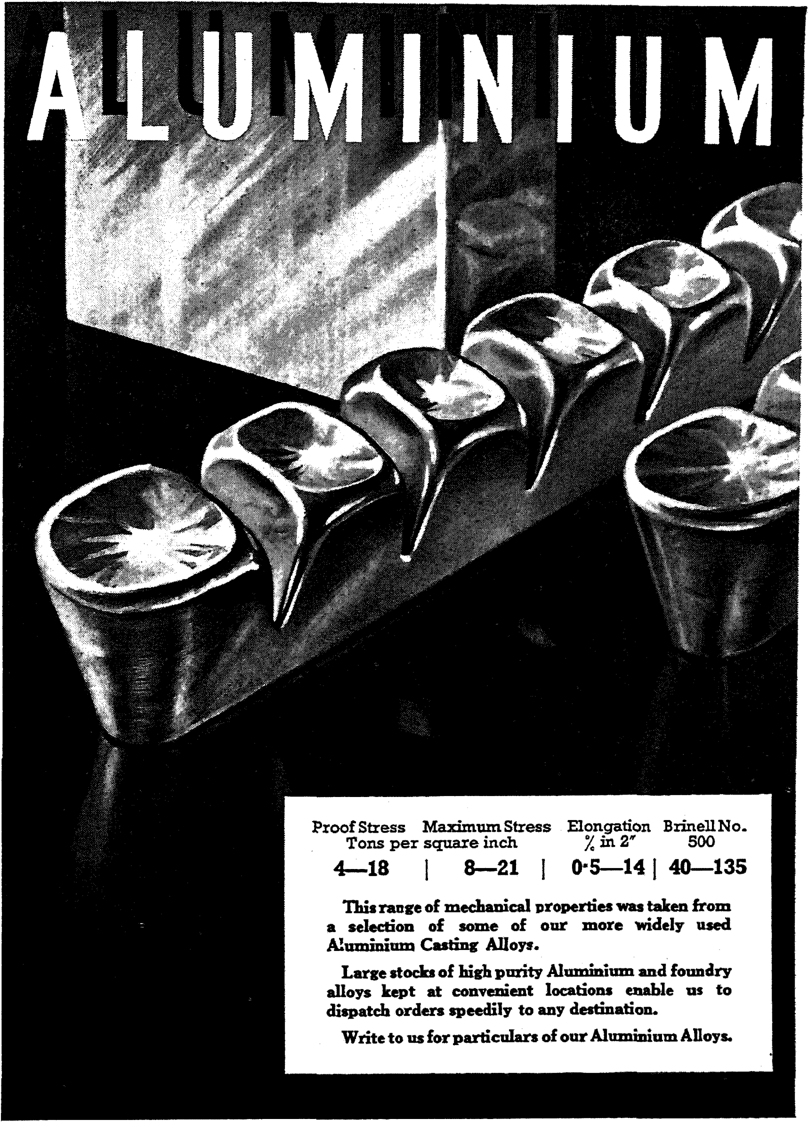

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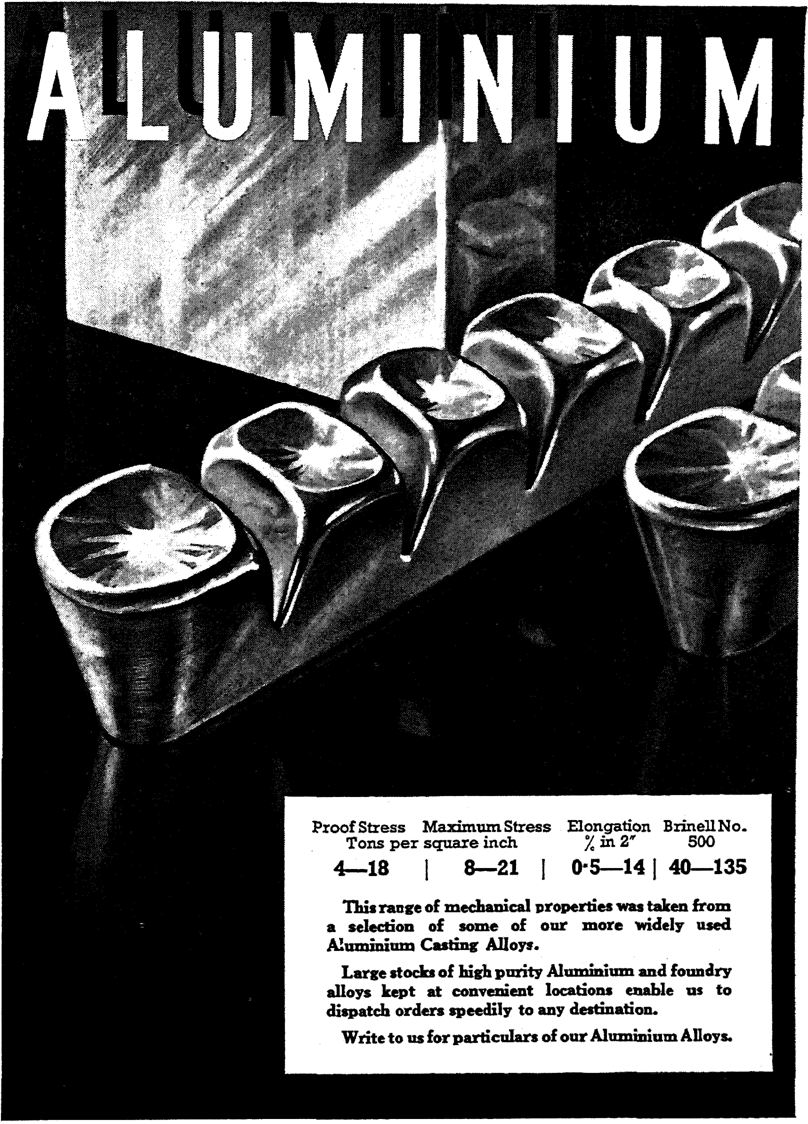

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